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A PORTABLE TEST BATTERY FOR COMPARATIVELY EVALUATING OPERATOR PERFORMANCE IN FULL-PRESSURE SUIT ASSEMBLIES

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FOREWORD

This study was initiated by the Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio 45433. The research was conducted by Applied Psychological Services, Inc., of Wayne, Pennsylvania 19087, under Contract F33615-67-C-1755. Arthur I. Siegel was the principal investigator for Applied Psychological Services. The work was performed in support of project 7184, "Human Performance in Advanced Systems," and task 718402, "Criteria for the Design and Arrangement of Controls and Control Systems." The research sponsored by this contract was performed between June 1967 and March 1968.

The task analysis for the F-111 aircraft was completed at the Systems Engineering Group, Wright-Patterson Air Force Base. In order to complete this analysis, Mr. Earl Sharp and Mr. Richard Geiselhart assisted in the completion of the administrative arrangements. Mr. Lee Fair of the Link Group of General Precision Systems, Inc., helped in the F-111 task analyses. The materials and manuals which we used to complete the two APOLLO based analyses were supplied by Mr. Earl LeFevers and Dr. Joseph Loftus, NASA, Manned Spacecraft Center. The arrangements for the completion of the analyses for the lunar exploration module were completed with the help of Dr. Clifford Seitz and Mr. James B. Trump of the Grumman Aviation Engineering Corporation.

At Applied Psychological Services, Philip Federman performed the field observations related to the performance of the F-111 task analysis. Dr. Mark G. Pfeiffer made criticality judgments of the F-111 tasks. Mrs. Gail Rush and Mrs. Estelle Siegel provided the needed administrative and secretarial assistance.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, Ph.D.
Technical Director
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ABSTRACT

Recommendations for a portable battery of tests to assess human mobility in full-pressure suits are presented. The literature was reviewed to determine the types of instruments and tests employed by prior investigators. Task analyses were performed on three advanced vehicles to determine the body member-movement families most frequently involved. A set of tests and measurements is suggested for those member-movement families found to be most frequently involved in advanced flight. Necessary future steps for realizing the portable battery are suggested.

The test battery recommended includes the Purdue Peg Board for finger dexterity, a specially designed apparatus for the strength of various body movements, a single dimension tracking task for various coordination tests, a Leighton Flexometer, and direct measurement devices for range of movement and static anthropology measurements.

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INTRODUCTION AND BACKGROUND

Since the early development of the full-pressure suit, which serves to protect the aviator or astronaut from low atmospheric pressure conditions, there has been a continued emphasis on evaluating the mobility and dexterity of an operator while wearing a suit. This emphasis was required because, no matter how well the low-pressure-protective requirements are met by the suit, utility of the suit is limited if the operator cannot perform his required tasks under conditions of suit pressurization.

Full-pressure suit designers continuously emphasized design modification to allow increased operator mobility. For example, early suit gloves contained wire restraints to prevent ballooning in the pressurized state. These restraints have been eliminated in later designs. Early, and to a large extent present, suits contain semirigid ring type assemblies to allow shoulder movement. These have been eliminated in some of the later full-pressure suits. Such redesign and development have produced mobility improvements in all suit components from the shoes, through the torso section, to the head assembly. Figure 1, which shows early and current full-pressure suit assemblies, yields some concept of the extent of the changes over the years.

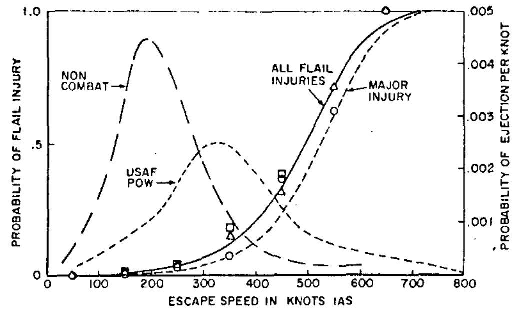
To test the extent of improvement brought about by one or more design modifications, tests have been performed of the mobility of the suited operator performing various acts within the partially or fully pressurized suit. Unfortunately, no standard methodology for performing the required measurements has evolved. Different aspects of mobility and dexterity have been measured at different laboratories, and different measurement techniques have been employed. Similar measurements may have been made, but suit pressurization allowed to vary; or, the experience and training of the operator in the suit may have been left uncontrolled. Thus, it is difficult to compare the mobility and dexterity afforded by the design aspects of one full-pressure suit with that allowed by a second, or to perform an overall comparative evaluation of two different suits.

Additionally, where standard measurement techniques have been proposed or employed, the techniques have often involved cumbersome and bulky equipment which imposed excessive set-up time and technician experience requirements.

NASA
S-65-38758

Figure 1. Early (Navy) 1953 and current (NASA) experimental full-pressure suit assemblies.

23-14



PROBABILITY OF FLAIL INJURY AND OF EJECTION AS A FUNCTION OF ESCAPE SPEED.

Fig. 18. Probability of non-combat flailing injuries as a function of escape speed (from ref. 24).

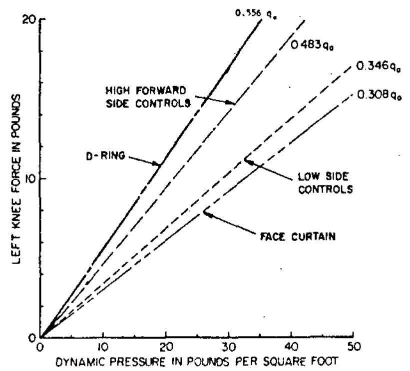


Fig. 19. Effects of ejection control handle position on knee separation force. (Data measured in wind tunnel on human volunteers in USAF flight clothing.) (from ref. 26).

Purpose of and Need for Present Study

The present study was undertaken to determine the content of a test battery which will allow assessment of motor performance in full-pressure suits under various conditions of suit pressurization, using a minimum of time and test equipment.

The Need

The need for such a test battery can hardly be disputed. It is presently possible to: (1) precisely specify the physical and structural requirements for pressure suits, and (2) measure the extent to which the equipment meets these specifications. The same cannot be said for the human performance requirements of the gear. The extent to which the human performance requirements are met is often left to subjective estimates by well-informed personnel.

Even though qualitative estimates of the perceptual-motor and manipulative ability of an operator wearing a full-pressure suit assembly are available, no standard objective method has been developed for precise, quantitative determination of the operator's capability. Accordingly, no minimally acceptable human factors capability or performance requirements specification can be written for full-pressure suit assemblies nor for other restrictive apparel. If the proper method were available, the human performance requirements of full-pressure suit assemblies could be specified quantitatively in a manner similar to that by which the physical and structural-design requirements are imposed, and it could be determined whether the suit design allows these human performance requirements to be met. Qualitative performance estimates would be replaced by quantitative, systematic performance measurements.

Further, a suitable performance measurement method would allow a determination, from the performance requirements point of view, of the relative superiority of several suits when all meet minimum structural design requirements. Finally, needed areas for improving the selected suit might become evidenced. From the alternate point of view, if the mobility and dexterity limits of performance in the full-pressure suit were known in quantitative terms, equipment designers could design equipment so that these limitations do not affect the operator's performance while wearing the full-pressure suit. For example, a study recently completed by Applied Psychological Services (1) indicated a greater inhibition of vertical movements than of lateral flexion and extension by the MARK IV full-pressure suit. Equipment operation sequences should, therefore, involve more lateral movements and fewer vertical movements.

In summary, an appropriate set of pressure suit mobility test instruments, if coupled with an appropriate set of administrative scoring and evaluative techniques, would:

1. allow precise, absolute, and comparative quantitative determination of operator capability in full-pressure suits and other flight apparel

2. allow the derivation of full-pressure suit and other flight apparel performance specifications and test the extent to which suits meet these specifications

3. provide a method for uncovering needed areas of improvement in full-pressure suits

4. be useful for evaluating the effects of pressure suit and other flight apparel design changes

5. be useful in research focusing on workspace and performance requirements in advanced aircraft

Background

Numerous studies have evaluated one or several aspects of the ability of the operator to perform various types of motor activity in full-pressure suit assemblies. However, there is little in the way of agreement among pressure-suit evaluators on which, if any, measurements should be emphasized or on how the required measurements should be performed. Many studies, which have dealt with mobility and dexterity, have been mainly *ad hoc* investigations of the utility of a specific suit under a particular set of conditions or in relationship to a specific equipment configuration. Within the literature, most attention has been paid to the workspace and the strength envelopes for the suited and unsuited operator. The definition of the workspace envelope afforded by the suit, however, tells us little about the mobility within the envelope and information about the force an operator is able to exert at the envelope's maxima and minima is of little pragmatic utility, since operators seldom work at these extreme limits. In general, prior studies which have attempted to quantify operator performance in a full-pressure suit assembly have included one, several, or all of the following measurements: mobility, workspace requirements, force exerted, static and dynamic anthropometry, psychomotor coordination, dexterity, and visual field limitations. Each of these is discussed separately in the succeeding sections of this chapter.

Mobility

Prior studies which have emphasized the methodology for assessing the mobility afforded by a full-pressure suit seem to have focused on: (1) definition of situations for testing the ability of the suited subject to perform gross and fine motor movements, and (2) the design of equipment for performing, in a sophisticated manner, the required measurements in these situations.

From the point of view of the actions or movements to be performed in the suit, Miller and Lincoln (2) proposed the following list: fall to a prone position, roll from the supine to the prone position, rise from the prone position to hands and knees, crawl forward, crawl backwards, rise to the seated position from the hands and knees, rise from hands and knees to upright position, lower to hands and knees from upright position, lower to deep squat from upright position, rise to upright position from deep squat, walk forward on a level grade at various speeds, walk sideways, walk up and down a staircase, jump down from a 1 foot height, climb up and down a ladder, and lift a weight and carry it away. However, Miller and Lincoln did not suggest any standard method for administering or scoring these tasks.

Marton (3) proposed a similar, but somewhat longer, list of tasks for gross body movement evaluation. He also added some methodological standardization for the tasks involved. Marton specified, for example, the distance and rate of the walking task, the number and spacing of the ladder rungs, etc. Scoring for each task was based on whether or not the subject could perform the task and, in some instances, the time to complete it. Siegel and Tabor (4) suggested timing the subject as he performs a standard operational task. They used the aircraft abandonment procedure for the F8U-1 aircraft as their task. In a similar vein, several gross mobility studies under zero-g and lunar-g have been conducted (5, 6, 7). The methodology employed in these studies is exemplified by the Simons, Walk, and Sears (5) study in which the subject was required to rise from a chair, make his way through an opening of variable diameter and sit in a chair on the opposite side of the opening. This scenario can, in a sense, be considered to be like the sequence involved in entering a hatch during space flight. The indication of adequacy, used in this study, was the ability of the suited operator to perform the task.

Alternative, and less modest, approaches to mobility measurement have used photographic recording techniques. Contini, Drillis, and Slote (8) discuss three optical techniques for making such recordings. All have been used with some success, especially in the measurement of rate of

movement. Motion pictures are the most common, perhaps with a clock included in the field of view to assist in later analysis. Interrupted light-stick diagrams depend on light reflected from "scotchlite" strips taped to the moving object, such as the segments of a limb, to expose the film. The light source is interrupted stroboscopically or with a mechanical shutter to provide a sequence of "sticks" on a single film while one complete motion cycle is completed. The individual sticks, thus, represent both positional and timing information. A sliding cyclograph uses essentially the same technique, except that the film is transported continuously behind the open lens while the motion is carried out. This method assists in analyzing repetitive motions which would otherwise overlap on the "stick diagram." All of these techniques can, of course, use synchronized cameras mounted in two or three orthogonal axes to obtain records of the movements in more than one axis.

Workspace Requirements

Related to, but different from, the mobility concept is the geometry of the area in which the various controls, and displays, which the suited operator must use, can be placed. Quite obviously, the equipment operator must be able to reach and manipulate all of his required controls and see the related displays. Two general approaches have been taken to this assessment. One is the determination of the limitations imposed by the pressure suit for a particular application or equipment system. Langford (9) conducted such a study on the mobility of aircrews wearing the A/P22S-2 and A/P22S-3 suits in F-101B, F-1-2A, and F-106A cockpits. Like other such studies (e.g., 4), Langford's study delineated the controls which were unavailable, or available to the operator only with difficulty. He also presented an overall evaluation of the criticality of the inaccessible controls. While such an approach yields specific answers regarding the utility of a particular operator-suit combination in a specific vehicle, more general information is usually needed to forecast the applicability of any given suit to any specified equipment configuration.

The usual approach to this more general evaluation has been to establish a functional reach envelope and/or a functional force envelope for the suit under consideration. The functional reach envelope is a three-dimensional representation of the space around the operator within which he is able to reach and to some extent operate controls. The strength envelope represents a similar concept, which presents some measure of the effort which the operator can exert at selected points in the work envelope. A discussion of the force envelope is presented in the next section of this chapter, along with considerations of other measures of strength.

Since reach envelope establishment represents an attempt to define the limits within which the operator can do useful work, not the maximum extremes he can reach, measurements of the reach envelope are usually taken with the subject actually grasping a control. One example of such work is that of Kennedy (42), who investigated, with an Air Force sample, the outer boundaries of grasping-reach envelopes for the shirt-sleeved seated operator. Many techniques have been developed for measuring this workspace. The Air Force System Engineering Group has used an approach (10, 11, 12) which establishes functional reach in each of three planes centered about the shoulder joint: frontal, horizontal, and parasagittal. The apparatus consists of calibrated radius rods arranged every 15° around an arc which can be mounted in any of the indicated planes. The suited subject's task is to grasp the handle on the end of each rod within reach and push the rod as far as he can, without releasing the handle.

An essentially similar system was used by Siegel, Bulinkis, Hatton and Lanterman (13), except that they used a single radius rod capable of being placed in any position along a calibrated perimeter. The perimeter was rotatable around any of the major axes to obtain intermediate reach distance values. Such a device also appears to be in use in the Crew Systems Laboratory at NASA (14). For their work envelope determination studies, the Aerospace Crew Equipment Laboratory has used an overhead gantry crane to position a probe at any point in space around a seated operator. Various techniques have been developed for using this facility (1,15). Pierce and Murch (16) used essentially the same technique, except that the location of points on the envelope were manually determined by reference to the floor and two orthogonal walls. An "ideal technique" for measurement of the reach envelope has been proposed by Parry, Curry, Hanson, and Towle (17). It involves rotating a pantograph mounted control handle around the subject at a constant velocity. Recording devices would then automatically record the reach distance for every angle of rotation, within a given horizontal plane, as the pantograph is free to move toward or away from the subject as required. The pantograph arm is then reset in elevation to sweep other horizontal planes. The device is designed to be "fail-safe," in that the control handle is magnetically attached to the pantograph. The proposed system envisions a fully automatic data recording and plotting facility.

All of the techniques so far mentioned have used some mechanical measuring technique for arriving at the dimensions of the reach envelope.

Photographic techniques for obtaining accurate data on the position or location, such as is necessary for establishing reach envelopes, usually suffer from measurement problems due to factors such as parallax, distortion, etc. Pierce (18) presented a photographic technique similar to the

stick diagram, except that the subject grasps a small flashlight while moving his arm through the outer limits of a given horizontal plane. To preclude distortions, a beam splitter (dichroic reflector) was used to superimpose the subject on a grid, mounted at right angles to the plane of motion, and the same distance from the lens.

Force

The third major area which has been of concern to investigators interested in objectively measuring the ability of the suited operator in a full-pressure, protective assembly is closely related to the two areas (mobility and workspace) discussed above. Having discovered the extent to which an individual can move about and reach within a pressure suit, investigators have also been interested in the degrading effects, if any, of the suit on the force the suited operator can exert.

The aspect which seems to have been of most concern is the force a suited operator can exert on hand controls. Not only are the greatest proportion of control actions performed by the hand, but those few which are foot controlled, such as the rudder and brakes, are usually well within the capability of even the operator in a fully pressurized suit. The leg is capable of considerably more force than is usually required of it.

Force has usually been stated in terms of the maximum momentary force which an operator can apply to a control under a given set of conditions. Sustained application of force has also been measured and has been referred to as endurance. Endurance has been assessed through the duration over which a force can be maintained. For most controls, momentary force is of primary concern. For some few controls, like stick and rudder pedals, endurance is equally important. Caldwell (19) indicated that endurance is a function of a person's strength, at least as far as static endurance for manual pull is concerned. The major force measures employed have been push, pull, hand grip, and rotational torque. Federman and Siegel (15) investigated rotary torque capability in the Navy Mark III pressure suit. They found that the range of torques which one is able to exert varies from a low of 6.25 inch-pounds under two pounds per square inch of suit pressurization to a high of 17.25 inch-pounds under zero suit pressurization. The lower limit was obtained 30° from the medial sagittal plane, 44 inches above the seat reference point. The upper limit was achieved at 30° from the medial sagittal plane at both 8 and 17 inches above the seat reference point. There was also a significant anthropometric group by suit pressurization condition interaction. Siegel and Lanterman (1) investigated rotary torque, under various suit pressurization conditions, as a function of knob diameter. The results indicated that the maximum force measurable by their apparatus

(184 inch-ounces) could be exerted by their subjects when a 1.27 inch-diameter knob was employed in any of the tested locations and suit pressurization conditions. When a 0.928 inch-diameter knob was employed, the subjects could exert near maximal torques only under ventilating pressure. The effect of 3.0 psi pressurization was to reduce the maximal torque the suited subject could exert to as low a value as 70 inch-ounces.

Huchingson (42) compared, among other factors, the grip strength allowed by the Mark IV and the Gemini suits, pressurized and unpressurzed. He found about a 35 percent decrement attributable to the suit itself. A further 12 percent decrement resulted from suit pressurization. Marton (3) recommended hand grip plus rotational torque and thrusting force measures as constituting a usable set of force measurements.

Pierce and Murch (16) investigated three measures of strength in the Mark IV suit: push, pull and torque. Using an adjustable seat, they plotted strength as well as reach envelopes for the seated (suit pressurized) as well as the supine (suit unpressurized) operator. Generally, their study was intended to be descriptive and not interpretive, particularly since their only subject was at the 20th percentile in stature and the 5th percentile in functional reach. The general human factors literature, particularly the work of Caldwell (19, 20, 21) and of Hunsiker (22) contains many suggestions on appropriate instrumentation and techniques for measuring force. These include the direct reading of dynamometers or torque meters or the provision of automatic recording kymographs reflecting the inbalance in bridge circuits or strain gauges attached to the control.

Anthropometry

Anthropometry, in general, refers to the science, or the technique, of measuring the physical proportions and shape of the individual human being. In the current context, it refers to the measurement of the various positions into which the suited operator can place his body and limbs. As such, these measurements are related to workspace requirements and to limb mobility. Anthropometric measurements can be separated into two classes: (1) static anthropometry, and (2) range of motion.

Static anthropometry, or the measurement of body members in rigid, standardized positions, is of relatively little concern to the evaluation of pressure suits <u>per se</u>. However, such measurements establish limits on the workspace which an operator can occupy and on the design of pressure suits as well as other personal gear. Of particular interest to the design (fit) of such gear are the report of Gifford (23) on naval aviators and the

report of Hertzberg, Daniels and Churchill (24) on Air Force flying personnel. Both of these studies represent fairly large sample, detailed tabulations of most conceivable static anthropometric measures of the kinds of individuals likely to be using pressure suits. Data are given for, but not limited to, such measures as those listed in Table I. Hertzberg et al. present similar data from a sample of Air Force flying personnel. Their data are also broken down by type of duty.

Table I

Typical Anthropometric Measures
(from Gifford et al., 1965)

Morphological Feature	
Weight	Waist Breadth
Stature	Hip Breadth
Tragion Height	Chest Depth
Cervicale Height	Waist Depth
Suprasternale Height	Buttock Depth
Nipple (Chest) Height	Hip Breadth-Sitting
Waist Height	Neck Circumference
Penale Height	Shoulder Circumference
Gluteal Furrow Height	Chest Circumference
Crotch Height	Waist Circumference
Patella Height	Buttock Circumference
Sitting Height	Buttock Circumference Sitting
Eye Height Sitting	Thigh Circumference
Shoulder Height Sitting	Lower Thigh Circumference
Elbow Rest Height	Calf Circumference
Knee Height Sitting	Ankle Circumference
Popliteal Height Sitting	Scye Circumference
Buttock-Popliteal Length	Axillary Arm Circumference
Buttock-Knee Length	Biceps Circumference
Shoulder-Elbow Length	Lower Arm Circumference
Forearm-Hand Length	Wrist Circumference
Functional Reach	Sleeve Inseam
Bideltoid Diameter	Sleeve Length (Spine-Wrist)
Chest Breadth	

In static pressure suit studies, measures have been typically taken of various circumferences, lengths, and widths at different suit pressures to indicate changes due to suit "ballooning." Bowen (25) and Rock (12) made such measures for the X-20 suit. Gillespie (10, 11) did similar work with the A/P22S-2 and A/P22S-2A suits. A typical result is given in Table II, which is taken from the Gillespie (11) study.

Table II

Dimensional Growth Caused by Inflation from 0.00 to 3.5 psi
(From Gillespie, 1966)

	A/P22S-2 (in.)	A/P22S-2A (MOD 1) (in.)
Axillary chest circumference	+ 3.80	+ 6.10
Waist circumference	+ 1.30	+ 4.90
Axillary arm circumference	+ 1.60	+ 1.80
Forearm circumference	+ 1.80	+ 1.80
Thigh circumference	+ 1.40	+ 1.80
Calf circumference	+ 1.30	+ 0.50
Shoulder breadth	+ 2.30	+ 5.25
Elbow-to-elbow (pressed)	+ 3.40	+ 3.95
Hip breadth	+ 0.40	+ 0.95
Posterior body plane - anterior knee area	+ 2.40	+ 6.55
Thigh clearance from floor	+ 0.50	+ 1.10
Sitting height	+ 2.10	- 0.25 (tie-down variability)
Arm reach from board	+ 0.85	+ 1.25 (gloves leave fingers)
Hand length	+ 0.25	+ 0.15
Finger tip to glove tip	+ 0.00	+ 1.60
Hand length from wrist ring	+ 0.65	+ 2.40

The range of motion of various body members, or anthropometric flexibility, is of greater concern to pressure suit assessment. One of the most frequent limitations imposed by pressure suits, especially when they are pressurized, is on joint flexion and, to some extent, on rotation. For example, Langford (9) noted that "rigid wrist rings" in the inflated suit prevented pilots from reaching the ejection seat D-ring. This type of deficiency was also noted by Naurath (26) and Siegel and Tabor (4).

Psychomotor Coordination

While it is difficult, in some cases, to distinguish whether the intent of an investigator was to measure psychomotor coordination or merely integrated finger-wrist-arm flexibility, or motor speed and accuracy, we have included under this topic studies in which the apparent aim was to measure precise coordination of a sensory or ideational process and a motor activity. We have reserved for discussion under the "dexterity" topic tests of speed and accuracy of simple manual activities. We note, however, that this dichotomy may not be entirely clear, meaningful, or useful.

Table III presents a list of some of the miscellaneous and sundry "tests" that have been employed to measure one or several aspects of psychomotor coordination. Most investigators have evidently believed that some measure of finger-wrist-arm control is required. Under this head we include such measures as reaction time, tracking, and simulated flight. Similarly, most, if not all investigators, have found that pressure suits and increasing suit pressurization tends to exert adverse effects on psychomotor activity, at least as represented by these tests. The validity of the laboratory type of test for predicting actual advanced flight performance has never been established, but one would anticipate a low, if not zero, predictive validity. Moreover, the meaning of an x percent increase or decrease in a steadiness or a tracking score, or in reaction time, as a function of suit design is not entirely clear. Nevertheless, the objectivity and administrative ease involved in these instruments seems to have served to cause them to be particularly popular.

Dexterity

The measurement and evaluation of some aspect of the manual dexterity of the suited operator in the full-pressure suit has occupied the attention of a large proportion of the researchers. A summary of some of the typical studies is presented in Table IV. Within the literature reviewed,

Table III

Tests, Measures, and Criteria Employed for Measuring Psychomotor Coordination in Full-Pressure Suits

Test	Investigators	Measure	Criterion
Work-space evaluator (6570th AMRL)	Gillespie (1965)	Disjunctive RT confounded with travel time	Percent increase in total time, pressurized *vs.* unpressurized
Work-space evaluator (6570th AMRL)	Gillespie (1966)	Disjunctive RT confounded with travel time	Percent increase in total time, pressurized *vs.* unpressurized
Work-space evaluator (6570th AMRL)	Sharp (1964)	Disjunctive RT confounded with travel time	Time
PEPSS computer	Miller & Lincoln (1964)		
Compensatory tracking, drift monitoring			Accuracy
Pattern comparison			Accuracy
Radio replacement under simulated weightlessness	Schuster (in Molesko, 1965)		Time
BSL work-space apparatus	Sharp & Bowen (1960)	Disjunctive RT	Time
APS-ZOOT	Siegel, Bulinkis, Hatton & Crain (1960)		
Psychomotor coordination		Compensatory tracking	Integrated error score
Rate of movement		Disjunctive RT	Time
Tapping board	Huchingson (undated)	Speed of arm movement	Scoring unspecified

Table III(con't.)

Pursuit rotary device	Huchingson (undated)	Eye/hand coordination in pursuit tracking	Scoring unspecified
Hole steadiness	Huchingson (undated)	Punctate (static) steadiness	Scoring unspecified
Groove steadiness	Huchingson (undated)	Dynamic steadiness	Scoring unspecified
F4B Simulator	Naurath (1963)		Accuracy of pilot performance
Blind angular bisection	Siegel & Lanterman (1967)		Average error
Pattern tapping test	Siegel & Lanterman (1967)		Time
APS-PAD	Siegel, Bulinkis, Hatton, & Lanterman (1963)		
Psychomotor coordination		Compensatory tracking	Integrated error score
Rate of movement		Disjunctive RT	Time
Simulated aircraft engine maintenance	Seeman, Smith & Mueller (1966)	Zero-G flight	Time

Table IV

Tests, Measures, and Criteria Employed for Measuring Dexterity in Full Pressure Suits

Test	Investigators	Remarks	Criterion
1. Purdue Peg Board	Bowen (1964)	Rotated board 180° for pressurized trials	Per manual
	Gillespie (1966)	Rotated board 180° for pressurized trials	Per manual
	Pierce (1963)		Per manual
	Walk (1964)		Per manual
	Huchingson (undated)		
	Jones (1966)	Rotated board for all trials	Percent decrement against 6 trial bare handed optimum
2. APS formboard and pegboard (ZOOT)	Siegel, Bulinkis, Hatton, & Crain (1960)	Manipulation, prehension, and dexterity	Accuracy right-wrong
3. Bennett Hand Tool Dexterity Test	Huchingson (undated)		Unspecified
4. Crawford Small Parts Dexterity Test	Siegel, Bulinkis, Hatton & Lanterman (1963)		Time
5. APS formboard II	Siegel et al. (1963)	Manipulation and prehension	Time

the Purdue Peg Board represents the most popular (frequently used) test. This test involves using the fingers to grasp, transport, and insert small pegs in holes, and to place collars around the pegs. The Crawford Small Parts Dexterity Test measures fine eye-hand coordination in using tweezers to insert small pins in close-fitting holes in a plate and to place small collars over the protruding pins. A second part of the test measures dexterity in placing small screws in threaded holes in a plate and screwing them fully down.

More gross dexterity seems to be involved in the measures provided by the Bennett Hand Tool Dexterity Test. The task involved in this test is to use wrenches and screw drivers to disassemble and reassemble a series of nuts, washers, and bolts.

Generally, the users have found these commercially available devices to yield an acceptable set of data and few, if any, difficult problems in their use have been reported.

Generally, it has been found that the unpressurized pressure-suit interferes with dexterity as measured. Moreover, measured dexterity varies inversely with suit pressurization. For example, Walk (27) found that Purdue Pegboard performance for the unpressurized A/P22S-2 suit was about 65 percent or less than that in the ungloved state. Pressurization of the suit to 2.5 psi caused a further decrement to about 35 percent or less of the measured dexterity of the ungloved hand.

Visual Field

Constriction in the visual field of the pressure suited operator can come about from limitations in the design of the head assembly or from a mobility restriction imposed by the design of the neck section of the suit. Early pressure suits possessed neck rings at the top of their torso section. The helmet, when worn, was attached to the neck ring via a "tongue in groove" arrangement. Rotation of the head allowed the surfaces to slide over one another and thus head rotation was permitted. However, this rotation was impeded because, among other things, of the friction between the two surfaces involved. Later suits adapted a "fish bowl" helmet concept which allowed unhindered neck rotation within the enclosure.

The extent of the visual field allowed by a full-pressure suit has constituted a continuous concern to suit developers. Early suit developers used informal tests such as seating a suited subject in a chair, pressurizing his suit, and asking him whether or not he could see objects in various locations around the room. Measures such as this obviously confound neck movement, head movement, shoulder movement, eye movement, and visual field restriction due to helmet design. Jones (14) has elaborated on this method by placing the operator in a specific system and determining whether or not he could see, under appropriate pressurization conditions, the equipments and indicators required to operate the system. In addition, he used an optical perimeter with the helmet fixed, but the head free to move within the helmet. Most other recent investigators also seem to have adapted some form of perimetry for accomplishing the required result. Here, an object is placed on a circular arm which rotates about its middle radius. The head is placed at the center of the sphere that the arm can describe, and a spherical projection of the field of view allowed by the suit is derived. This procedure has been employed by Bowen (25), Rock (12), Federman and Siegel (15), and Siegel, Bulinkis, Hatton and Crain (28). A typical result taken from Federman and Siegel (15) is presented in Figure 2.

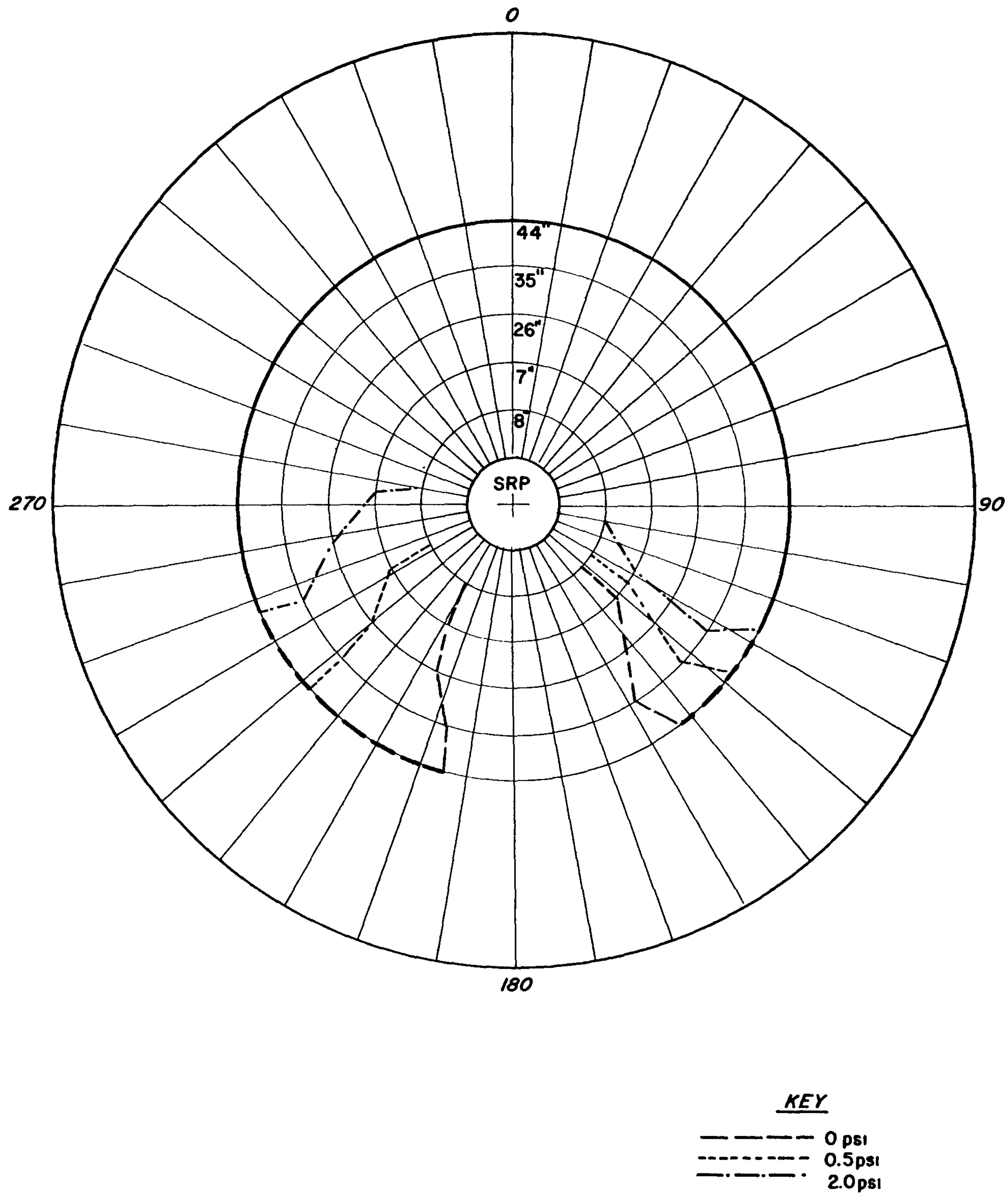


Figure 2. Mean visual field under various suit-pressurization conditions.

SECTION II

DATA SUBSTRATE

As indicated from the literature survey included in the first chapter of this report, most previous studies have aimed to establish a set of data for a given suit configuration, with little regard for whether or not the obtained measurements are relevant to the task of the operator. The logic for the present study was based on the assumption that a systematically drawn set of pressure suit evaluative measures should be based on and drawn from the motor acts performed by the operators of advanced flight vehicles. Thus, any selected measures would possess relevance for and be referenced to the actual job. And, any measurement technique which fails to possess relevance to the situation to which it will be referenced must be considered to lack utility.

Since one of the aims of the present study was to develop a method which possesses general, rather than specific applicability, simulation of the specific tasks performed in one unique aircraft type or in one spacecraft was considered inappropriate. In selecting a measurement battery, we were interested in reflecting those performance aspects which seem to constitute the common core of the perceptual-motor and manipulative tasks to be performed on most, if not all, advanced missions. Thus, based on a requirement of general applicability, the method proposed should not become obsolescent in the immediate future. If the alternative approach, basing the method on a specific space mission were employed, data more directly applicable to the selected spacecraft or mission would be derivable, but general laws, comparisons, and specifications would not be possible. Moreover, in most previous programs, personal equipment has been of a general issue nature and not specifically designed for any one program. The design philosophy behind pressure suit development has, by and large, paralleled this logic. Accordingly, rooting a measurement scheme to a specific equipment system or mission would be most inappropriate.

In order to develop the required insight into the actions performed by the operator of advanced vehicles, a number of task analyses were performed on operator-equipment systems which are representative of those in which pressure suits may be used. The analyses emphasized the motor, manipulative, and body movement activities involved in operating and performing various functions within the equipment systems. The analyses resulted in data on the amount and kind of movements typically performed in these systems. Such data provided a realistic framework within which to make decisions on what body movements to measure in evaluating performance capability in pressure suits. Then, a set of tests and measures for assessing the ability of the operator to perform these movements in full pressure suits could be selected.

Task Analyses

The basic intention of the analyses was to isolate the human motor actions performed in a variety of circumstances in which full-pressure suits would be worn, both pressurized and unpressurized. The activities within the analyses, therefore, were to represent as broad a spectrum as possible.

Accordingly, analyses were completed for three separate vehicles and for subsets of activities within each vehicle. The vehicles and subsets of activities were:

1. F-111 aircraft
   a. Take-off
   b. Cruise
   c. Emergency and infrequently performed procedures

2. APOLLO/ LEM vehicle
   a. Docking maneuver
   b. Intravehicular tunnel transfer

3. Grumman Mobile Lunar Base Vehicle
   a. Start
   b. Transit
   c. Shut down

Format and Content of Task Analyses

Since the aim of the task analyses was to document the kinds of body movements typically performed by each body member, the task analyses were oriented in terms of the movements performed by each body member during the performance of each act in each task subset. Accordingly, a movement type by body member matrix was prepared to be used in the performance of the task analyses. This matrix is presented as Table V. In Table V, each row-column intersect containing a check indicates a movement (column) which can be performed by a given body member (row).

On the basis of the variety of body member/ movements possible, a data collection form for the prospective task analyses was prepared. A sample of this form is shown in Table VI. The form in Table VI is also partially completed with data representing the first task analysis conducted, the F-111 take-off. For this analysis, a member of Applied Psychological Services' staff observed the performance of the subsets of sequences as they were performed, in a step-by-step manner, in the F-111 dynamic flight simulator at the Wright-Patterson Air Force Base. Using a previously developed code (shown in Table

Table V

Body Member by Movement Matrix*

Movements

Body Members	Abduction	Adduction	Circumduction	Depression	Elevation	Flexion	Extension	External Rotation	Internal Rotation	Pronation	Supination
1. Fingers (Thumb)			✓	✓	✓	✓	✓				
2. Wrist	✓	✓	✓			✓	✓				
3. Elbow (Forearm)						✓	✓			✓	✓
4. Shoulder	✓	✓	✓			✓	✓	✓	✓		
5. Hip	✓	✓				✓	✓	✓	✓		
6. Knee						✓	✓	✓	✓		
7. Ankle	✓	✓				✓	✓				
8. Neck						✓	✓	✓	✓		

*Checked cells indicate movement which may be performed by each body member.

Table VI

Sample Data Collection Form

System F 111 Phase of Operation Take Off Date 7/11/67

Subtask Number	Subtask Description	1 Control Type	2 Nature	3 Body Members	4 M-S	5 Movement Type	6 Criticality	7 Performance Criterion	Remarks
1	Air Starter	D3	S	A	M	F	2	B	Right
				B	S	G		B	
				C	S	G		B	
				D	S	G		B	
2	Start Engine -	E5	S	A	M	F	4	B	Left
	Right Throttle			C	S	$\underset{\leftrightarrow}{F}$		B	
				D	S	$\underset{\leftrightarrow}{\overset{A}{G}}$		B	
3	Start Engine -	E5	S	A	M	F	3	B	Left
	Left Throttle			C	S	$\underset{\leftrightarrow}{F}$		B	
				D	S	$\underset{\leftrightarrow}{\overset{A}{G}}$		B	
4	Left Generator On	D3	S	A	M	F	4	B	Right
				B	S	G		B	
				C	S	$\underset{\leftrightarrow}{F}$		B	
				D	S	$\underset{\leftrightarrow}{F}$		B	
5	Right Generator On	D3	S	A	M	F	3	B	Right
				B	S	$\overset{A}{G}$		B	

VII), the appropriate data for each complete sequence of control operations involved in the three phases of flight were documented. This documentation involved completion of the first five columns (control type, nature of control action, body member(s) involved, number of same body members involved, and type of movement involved) of Table V. Table V shows that the first subtask in the sequence involved actuation of the air starter. The entries reveal that this control is a three-position toggle and that the operation is single and involves several fingers, the wrist, elbow, and shoulder. In performing this action, the fingers are flexed and the other body members are extended. The final column (remarks) indicates that the act is performed with the right hand.

These data were recorded while observing the operator perform the various acts. The criticality data (column 6) and the performance criterion data (column 7) were completed subsequent to the observational sessions. The performance criterion data were entered in consultation with the operator who demonstrated the task sequences. The criticality data were supplied by a former Air Force jet fighter pilot who is a member of Applied Psychological Services' staff.

The APOLLO oriented analyses were performed from detailed task analytic data published in NASA APOLLO operations handbooks for block II spacecraft (1967). A mockup was employed to obtain deeper insight into some of the control actions involved and the performance criterion and the criticality data were based on the best judgment of the present investigators, as inferred from the handbooks and related publications available. The aspects of the APOLLO/LEM mission chosen for analysis were the docking maneuver and the intravehicular tunnel transfer to the lunar module. These segments were chosen because they represent a wide variety of critical control actions, as well as gross body movements. These sequences also involve both the pressurized and unpressurized suit conditions. The analysis stopped short of actual operation of the lunar excursion module and, hence, involved only controls in the spacecraft itself.

The final task analyses were completed at Grumman Aircraft Engineering Corporation's Peconic Bay, Long Island facility, where a full-scale, simulated lunar terrain and a full-scale working version of a mobile lunar base vehicle were available. The vehicle was not fully instrumented, but all motion controls, communication equipment, and external television scanner were installed and functioning. In this vehicle, acceleration, steering and braking were accomplished through a single side arm controller of unusual design. Otherwise, more or less conventional controls were employed. The phases of operation analyzed were vehicle start, transit, and shutdown. The task analyses were performed in a manner which paralleled that described above for the F-111 aircraft but, in this case, site personnel assisted in the assignment of the criticality, as well as the performance adequacy entries.

Table VII

Codes for Recording Task Analytic Data

Column	Code	Meaning
1. Control type	A	Detented rotary (number of positions)
	B	Continuous rotary
	C	Push button
	D	Toggle (number of positions)
	E	Lever
	F	Wheel
	G	Joystick
	H	Pedal
	I	Trigger
	J	Thumb wheel
	K	Trim tab
	L	Track ball
	M	Pull knob
2. Nature of control action	S	Single
	M	Multiple
	C	Continuous
3. Body member(s)	A	Fingers
	B	Wrist
	C	Elbow
	D	Shoulder
	E	Hip
	F	Knee
	G	Ankle
	H	Neck
4. Number of same body members involved	M	Multi member
	S	Single member
5. Movement type	A	Abduction
	B	Adduction
	C	Circumduction
	D	Depression
	E	Elevation
	F	Flexion
	G	Extension
	H	External rotation
	I	Internal rotation
	J	Pronation
	K	Supination

Table VII

Codes for Recording Task Analytic Data (con't.)

Column	Code	Meaning
6. Criticality	1.	Unimportant, but system and/or mission augmenting
	2.	Important, but not directly failure inducing
	3.	Must be done or mission <u>or</u> system failure ensues
	4.	Must be done or mission <u>and</u> system failure ensues.
7. Performance criterion	A	Time
	B	Accuracy
	C	Both

Results

All data from three sets of task analyses were tabulated, with particular attention to the body member and movement types involved. In all, 1,812 movements were examined involving 37 different body member-movement type combinations. Thirteen of these combinations were common to all systems examined. The body member-movement types common to all systems are represented in Table VIII.

Table VIII

Combinations of Body Member-Movement Types Common to All Systems Analyzed

Body Member	Abduction	Adduction	Extension	Flexion	Depression	Elevation
Finger				✓	✓	✓
Wrist	✓	✓	✓	✓		
Elbow			✓	✓		
Shoulder	✓	✓	✓	✓		

Since abduction-adduction, extension-flexion, and depression-elevation are opposing actions involved in body member-movement, Table VIII may obviously be reduced to seven combinations. These seven combinations are "boxed" in Table VIII and probably represent the great majority of control actions for most vehicular systems.

Within the families of movement types, the flexion-extension movements constituted the principal component and accounted for 68 percent of the total. Table IX presents the distribution of movements for all systems combined.

Table IX

Percentage of Each Movement Involvement Across all Systems Investigated

Movement	Percent	Movement	Percent	Total Percent
Flexion	34	Extension	34	68
Abduction	5	Adduction	8	13
Depression	5	Elevation	4	9
Pronation	5	Supination	4	9
Internal Rotation	< 1	External Rotation	< 1	1

Body Members Involved

Within the present systems, the shoulder, elbow, wrist, and fingers accounted for 97 percent of the body member involvement. The distribution was approximately uniform across the four members. The percentage of involvement of the various body members is presented in Table X .

Table X

Percentage Involvement of Major Body Members for All Systems Investigated

Member	Percent
Shoulder	27
Elbow	21
Wrist	24
Fingers	25
Hip	1
Knee	1
Ankle	1
Neck	< 1
	Σ 100

Type of Action

Across the three vehicle systems, approximately 90 percent of the subtasks were "single," that is, they involved a single discrete control action, rather than a continuous control function. Of the 22 continuous subtasks identified,

most concerned vehicle attitude or speed control (stick, throttle, side arm controllers). All, except the F-111 rudder pedal related acts, were hand-arm actions.

In addition, only two percent of all the control actions tabulated required the conjoint action of right and left body members. When conjoint action was noted, it was principally involved in rudder pedal and brake operation.

Relative "Importance" of Various Body Member - Movement Combinations

To assess the relative "importance" of the various combinations of body members by movement types, the 13 combinations common to all three systems were examined separately for the three systems. In Table XI, the importance values shown for each combination and each system represent the summed products of the frequency of occurence of each body member-movement type combination and assigned criticality of the subtask involved. For example, in the finger depression cell for the F-111, the importance value 59 represents 4 actions with a criticality rating of 4, 3 with a rating of 3, 16 with a rating of 2, and 2 with a rating of 1.

The sum of the frequency by criticality ratings is thus: $(4 \times 4) + (3 \times 3) + (16 \times 2) + (2 \times 1) = 59$.

The data of Table XI were further reduced and combined into the seven "families" of movements and body members. The results are presented in Table XII, where the importance values are ranked by "family" within each of the three systems.

On the basis of the data of Table XII, a coefficient of concordance (W) among the three systems was calculated. The coefficient of concordance is a statistic which is interpretable in a manner which is similar to a rank order correlation but, while the rank order correlation represents the degree of association between two variables, measured in, or transformed to ranks, W expresses the degree of association among a larger number of such variables. The resulting W value was .79. This value is statistically significant at the .05 level of probability and indicates fairly high agreement among the results obtained for the three systems involved.

For the same data, rank difference correlation coefficients were also calculated between all pairings of three systems involved. The resulting values were:

APOLLO-F-111: $R_s = .66$
APOLLO-Lunar vehicle: $R_s = .74$
F-111-Lunar vehicle: $R_s = .71$

Table XI

Relative Importance Values (frequency x criticality ratings) of the Body Member by Movement Types Common to all Systems

Body Member	Movement Type	APOLLO	System F-111	Lunar Vehicle
Finger	Depression	30	59	8
	Elevation	6	24	4
	Flexion	87	155	37
Wrist	Abduction	34	23	4
	Adduction	21	10	14
	Flexion	15	28	17
	Extension	28	55	6
Elbow	Flexion	29	53	16
	Extension	78	153	10
Shoulder	Abduction	6	46	4
	Adduction	22	52	17
	Flexion	26	86	8
	Extension	81	130	16

Table XII

Ranked Importance Value (frequency x criticality ratings) of the Body Member by Movement Type "Families"

Body Member - Movement	System: APOLLO	System: F-111	System: Lunar Vehicle	Mean
Finger				
Depression-elevation	6	5.5	7	6.2
Flexion	3	3	1	2.3
Wrist				
Abduction-adduction	4	7	6	5.6
Flexion-extension	5	5.5	4	4.8
Elbow				
Flexion-extension	1.5	2	2	1.8
Shoulder				
Abduction-adduction	7	4	5	5.3
Flexion-extension	1.5	1	3	1.8

The rank difference correlation coefficients are all of about the same order of magnitude and again suggest fairly close compatibility between the importance values of the various pairs of systems.

SECTION III

PORTABLE TEST BATTERY

The first section of this report attempted to set into focus those tests and measures which have been employed by prior investigators to investigate the effects of full-pressure suits on various body actions. The second chapter attempted to define and clarify those body actions which are used most frequently and which are most important for performance in advanced vehicles. Section III attempts to bring these two sets of information together so as to define the requirements for a portable test battery capable of providing appropriate measures of operator capability in full-pressure suits.

The adopted measurement scheme must possess a number of attributes if it is to be useful.

First, the technique must lend itself to standardization. Standardization implies both standard administration or task presentation and standard, objective scoring.

Second, the complete administrative time for measuring the performance allowed by any one suit must be "reasonable." Reasonable administrative time is a practical criterion that is difficult to bound or abstractly delimit. However, an administrative time of 2 hours does not seem to be outside the bounds of normal expectancy. This administrative time is considerably less than that devoted to and involved in other tests of the physical adequacy of equipment.

Third, the task administration and scoring must be reasonably simple. A technician, after a brief period of training, should be able to conduct both the measurements and scoring. Administrative and/or scoring methods which involve detailed administrator training are uneconomical and are impractical in periods of low technical manpower availability.

Fourth, tasks involved in the measurement method should be reliable. Reliability is used here in both the engineering and psychometric senses. Obviously, equipment which fails frequently or which is difficult to return to the operational status once it has malfunctioned is not acceptable. Similarly, the measurement methods which form the substrate of the evaluative process must give consistent results when applied to the same person in the same pressure suit on different occasions, or when employed by different test administrators on the same occasion.

Fifth, the method must be valid. At the outset, the validity, or the extent to which the method measures what it is supposed to measure, must be construct validity rather than empirical or statistical validity. Construct validity is the extent to which the measures involved sample the important functions or processes involved in the perceptual-motor and manipulative aspects of pressure-suit utilization. The predictive validity of the method, or the extent to which a total score derived from the method correlates with inflight performance can only be established after the technique is fully developed.

Sixth, within the ground rules established for the present study, the method must be portable. Portability implies freedom from bulkiness, lightness and lack of need for special power supplies or exotic electrical requirements. Moreover, a large device which can be broken down into a number of parts, each of which is portable, cannot be considered to meet this portability requirement.

Seventh, the tests employed should, if possible, be commercially available. This constraint, while imposing certain limitations on the "soul" of the emerging battery, yields a number of advantages. The cost savings involved in "commercial" acquisition, as compared with specially fabricated devices, is self-evident. Moreover, as indicated in Section II, there has been little standardization among the approaches employed by various governmental laboratories and commercial establishments involved in evaluating pressure suits from the operator's point of view. Accordingly, comparison of the results obtained at one laboratory with those obtained at another is difficult, if not impossible. Use of commercially available tests, within an evaluative battery, would help to bring about such required standardization.

Test Battery

Table X indicated that 97 percent of the body member involvement, within the tasks and systems included in our analyses, was concerned with the shoulder, elbow, wrist and fingers. Hip, knee, ankle, and neck movement were minimally involved. We note, however, that the involvement of these members might be greater in walking, exploration, and other similar tasks. Tasks of the walking and exploration variety were not included in our analyses. The data were further reduced and converted to ranks, as presented in Table XII. The final column of Table XII presents a mean ranking across each movement type row. Our logic is to dichotomize this column of rankings at the mean (3.8) and to label those body member-movement families which fall above the mean as Level I areas; those which fall below the mean are termed Level II areas. Other body member-movement involvements (ankle, knee, foot, torso, etc.) are termed Level III areas. This logic yields the grouping shown in Table XIII.

Table XIII

Grouping of Body Member-Movement Families

Body Member	Level I	Level II	Level III
Shoulder	flexion, extension	abduction, adduction	
Elbow	flexion, extension		
Wrist	abduction, adduction	flexion, extension	
Finger	depression, elevation	flexion	
Ankle, knee, foot, torso, neck, head, palm, etc.			various

Within each level, we consider a series of measurements, each of which will yield a separate indication of the ability of the pressure-suited operator to perform the required movements. Tests, applicable to the Level I grouping, are suggested for employment in all evaluations. The investigation of Level II characteristics might be carried out only if a particular operator-suit combination seems acceptable from the points of view of the Level I measurements. The LevelIII measurements become involved only after "acceptable" Level I-II performance is found or if a particular proposed mission is heavily weighted in the actions subsumed by this grouping.

The logic suggested for splitting Level I tests from Level II tests is modified in Table XIII in two instances. Both wrist movement measures would have fallen into Level II by the suggested logic since their ranks are below the mean cut point. The 2 finger measures would have been tested in the opposite levels. The modified grouping in Table XIII is a compromise designed to insure a representative variety of movement types in Level I and to insure that each body member is sampled. This is especially important if testing is terminated after Level I tests are completed. The ultimate user may, of course, make his own arrangement of tests by levels.

Areas of Test

For evaluation within both Levels I and II, the literature has suggested a number of possible measurement areas. These include dexterity, strength, coordination, range of body member-movement, and static anthropometry. However, not all test areas are believed appropriate for all body member-movement combinations. Those test areas which are believed applicable to each body member-movement combination are discussed below.

Level I Tests

Table XIV synthesizes the isolated body member-movement families and test areas suggested for measurement for the various row-column intersects.

Finger Measures

For the finger, and specifically to measure dexterity, we suggest the Purdue Peg Board. We note, however, that this measure will also involve some confounding with finger flexion. This test possesses a history of use in pressure-suit evaluation, is simple to administer, yields an objectively derived score, and is commercially available. The pegboard consists of a row of 4 small wells which contain pins, collars, and washers. Perpendicular to the row of wells are 2 parallel rows of small holes. The subject is required to assemble, in each hole, a set consisting of a pin, a collar, and a washer. In the current case, we suggest measurement of only preferred hand dexterity on the basis of the number of pin-washer-collar combinations completed in 60 seconds. Three 60 second trials are suggested per suit pressurization condition.

The trial to trial reliability of the test has been variously estimated to range between .60 to .91 [Gekoski (29)]. These reliability values are based on 2.5 minute trials and lower trial reliability values can be anticipated with a 1 minute administrative time. Complete administrative instructions are contained in the manual provided with the test. The Purdue Peg Board is available from Science Research Associates, Inc., Chicago, Illinois, at approximately $32. It is estimated that 15 minutes will be required to administer the test, assuming three suit pressurization conditions.

Measurement of finger depression-elevation strength cannot be accomplished, to our knowledge, through the use of any commercially available apparatus. For this measurement, we suggest the development of a simple apparatus, such as that shown in Figure 3. In use, the suited operator would first place his thumb in the slotted groove and, with his wrist held firmly on a table top, depress the lever by using a depressing thumb motion. Data are recorded from the direct reading dial in either inch pounds or inch ounces. The operation is then repeated for the index finger and then the middle finger. Now, the sequence is repeated in the order: middle finger, index finger, thumb, and the rotation is continued until five measures are obtained for each of the three fingers. It is estimated that the administrative time for this test will be about 15 minutes.

Table XIV

Summary of Suggested Level I Tests

	Measurement Area and Test/Device				
Body Member-Movement	Dexterity	Strength	Psychomotor Coordination	Range of Movement	Static Anthropometry
Finger depression-elevation	Purdue Peg Board	Special apparatus	One dimensional tracking with finger control	Direct measurement	Direct measurement
Wrist abduction-adduction	Special apparatus	Special apparatus	One dimension tracking with control knob	Direct measurement	------------
Elbow flexion-extension	---------------	Special apparatus	One dimensional tracking with stick control	Leighton Flexometer	Direct measurement
Shoulder flexion-extension	---------------	---------	--------------	Leighton Flexometer	Direct measurement

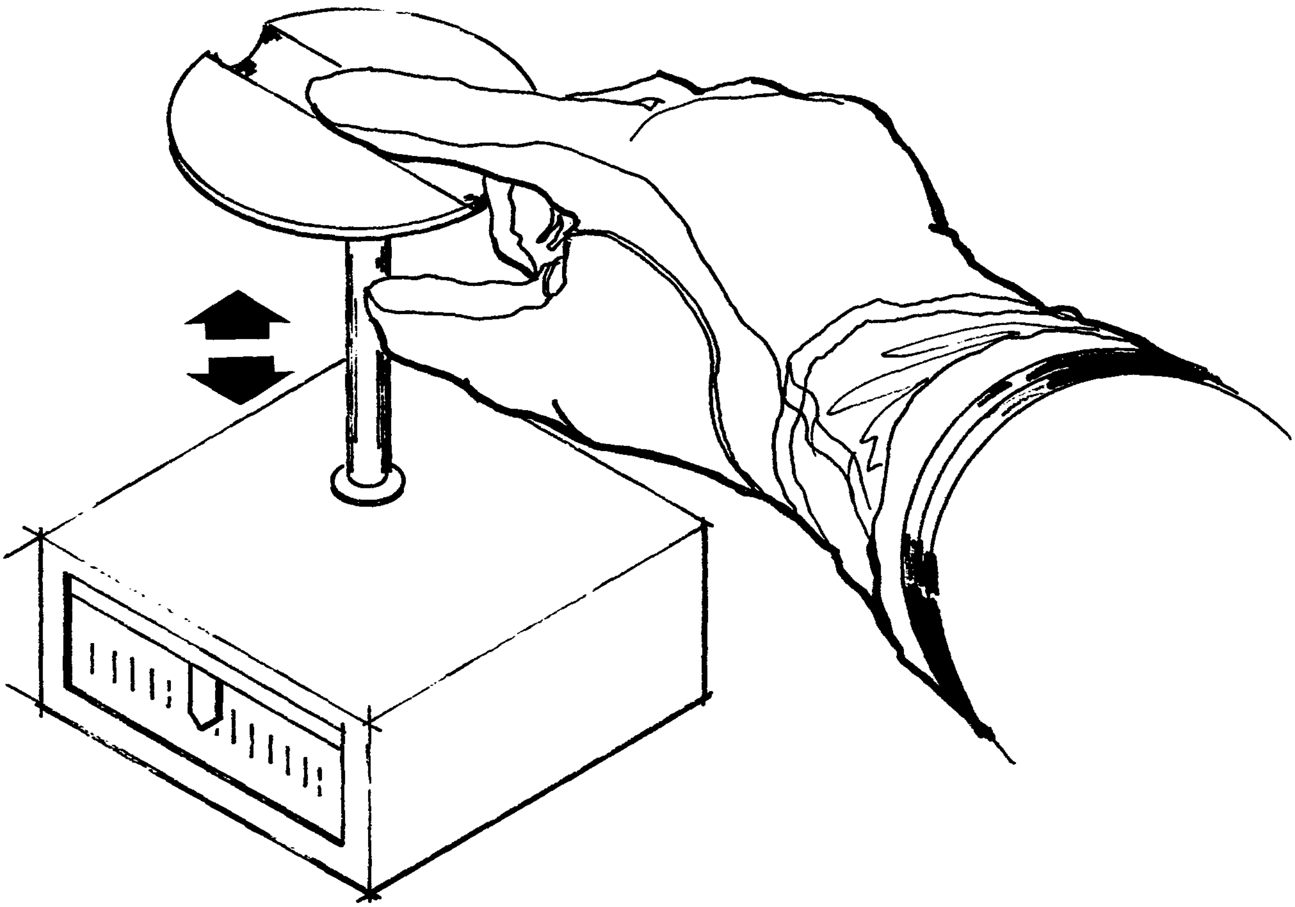


Figure 3. Device for measuring finger depression-elevation strength.

Psychomotor coordination for finger depression-elevation is measured through a one-dimensional compensatory tracking task employing a slide control*. In use, the slide controller is placed vertical to the fully extended index finger of the suited subject, and 1 minute of tracking is performed. This tracking is then repeated, employing the middle finger. The 1 minute tracking periods are continued, alternating each trial over the index finger and middle finger, until 3 trials have been completed with the index finger and 3 trials have been completed with the middle finger. Integrated time off target is recorded for each trial and the mean obtained for each of the 2 fingers involved. Assuming 3 suit pressurization conditions, administration of this task will take about 15 minutes.

To measure the range of finger depression-elevation for the suited operator, we suggest the use of a simple millimeter ruler. The method of measurement is demonstrated in Figure 4. The first measure is taken with the index and middle fingers of the preferred hand fully extended. The second is taken with the knuckles fully flexed. The two measures are made, under each condition of suit pressurization, in millimeters. The measures are taken with the bottom of the fingers as the references. Thus, suit ballooning, if present, will affect each measurement equally. It is estimated that 10 minutes will be required to complete these measurements.

To measure static changes in the finger dimensions brought about by the suit, we suggest direct tape measure measurement around the extended preferred hand, at the joint between the first and second phalanges, under various suit pressurization conditions. The measurement should consume no more than 5 minutes.

Wrist Measures

It is suggested that wrist dexterity be measured through a simple paper and pencil technique, as illustrated in Figures 5 and 6. Essentially, an aiming task, based on separate measurement of abduction and adduction, is suggested. The preferred arm is placed in a standard position, as illustrated in Figure 5. A target holder is placed 2.5 inches to the left of the suited subject's thumb and middle finger. The central dot of the pattern is set at the same height above the table top as his thumb. The task of the subject is to abduct fully his wrist and then, via an adducting aiming

* A number of tracking tasks are described throughout this report. Each is based on compensatory tracking involving different body members and different movements. The design for a modularized device which will produce these various required control situations is presented in the Appendix.

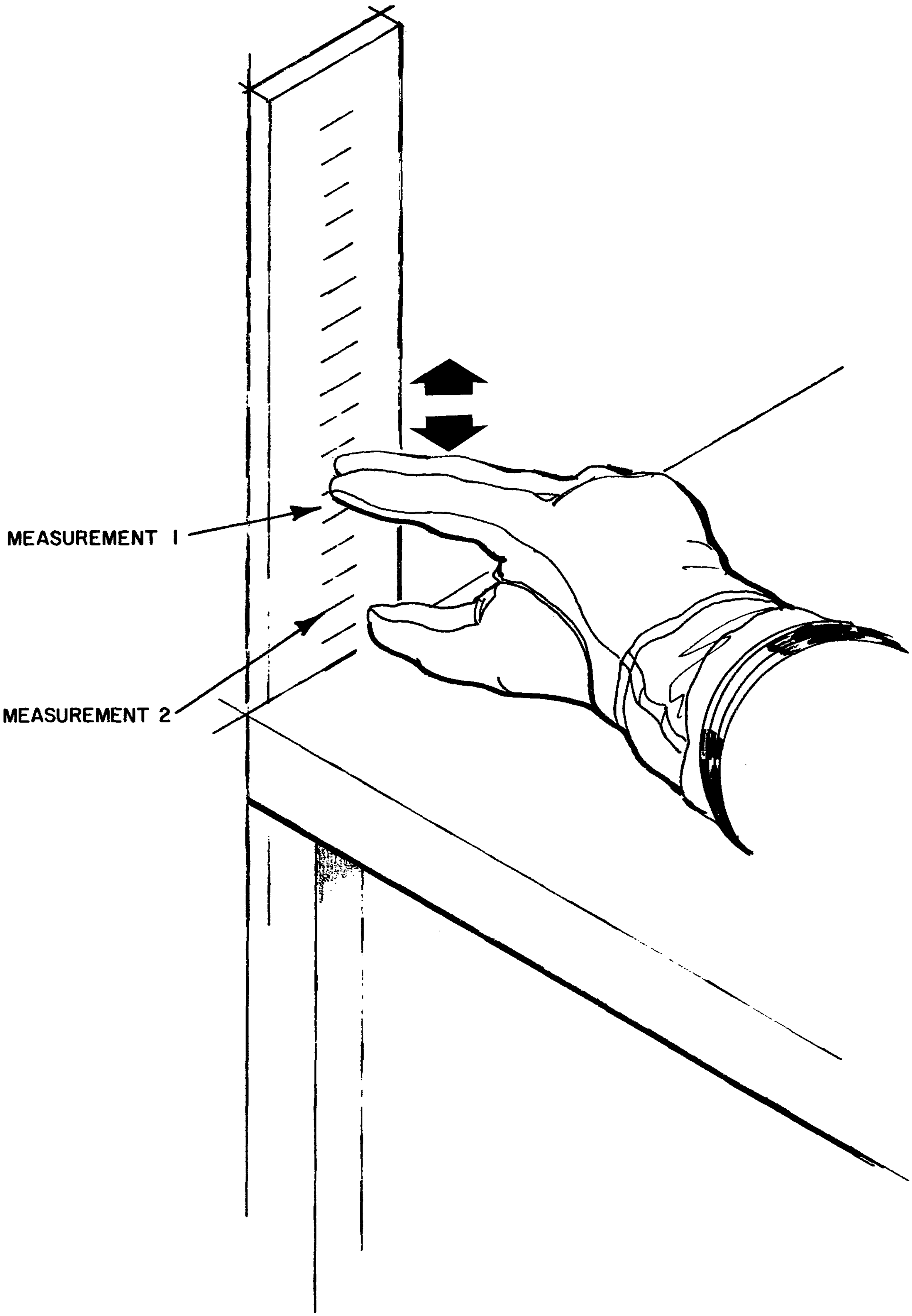


Figure 4. Measurement of finger depression-elevation range.

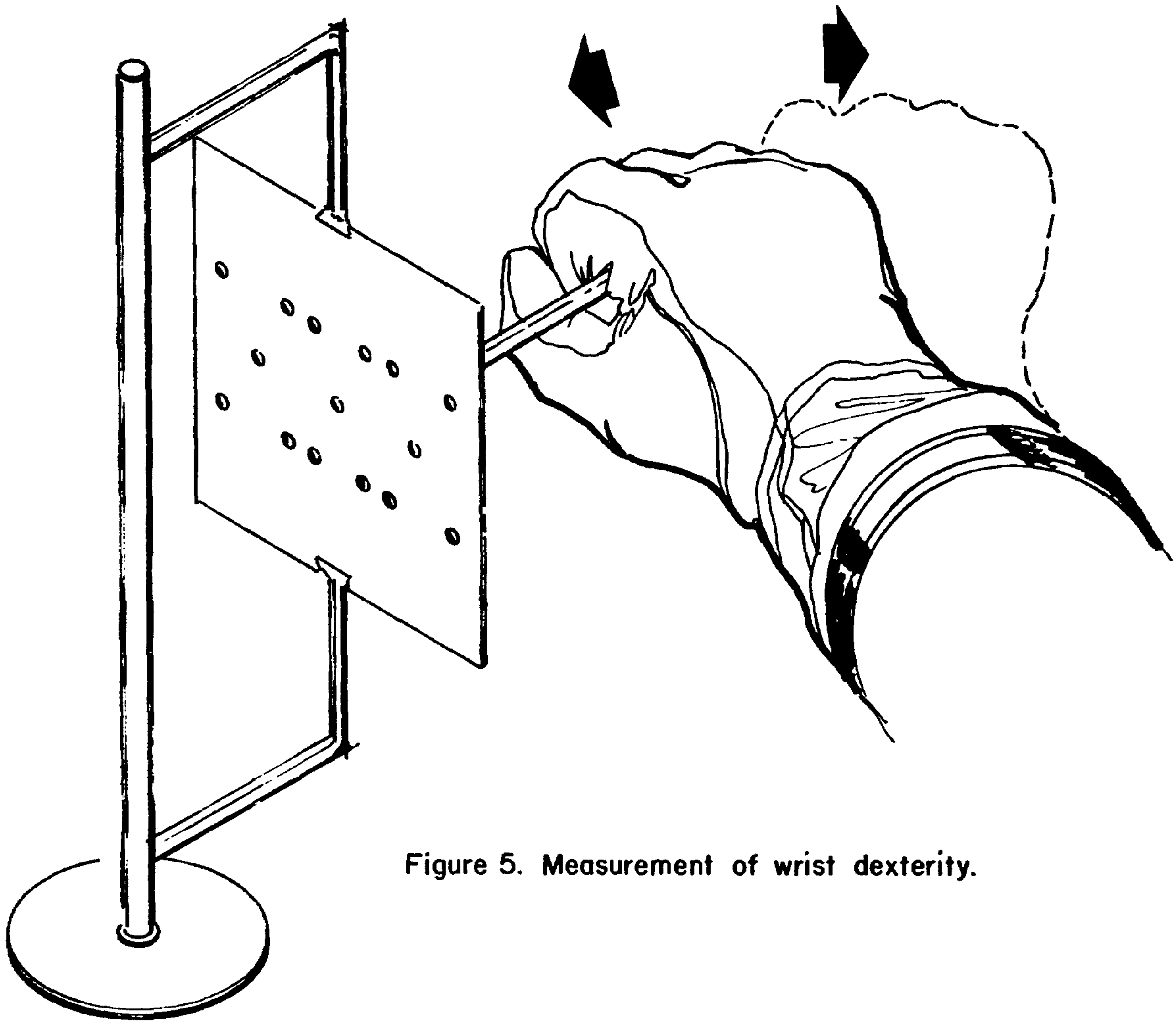


Figure 5. Measurement of wrist dexterity.

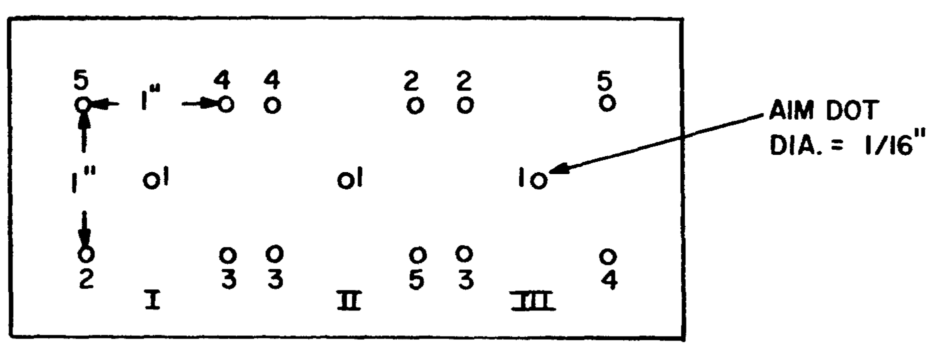


Figure 6. Design of response pattern template for wrist dexterity measurement.

motion, hit the "number 1" dot of a patterned set with the pencil point. He then fully abducts his wrist and aims for the "number 2" dot, using an adducting motion. This procedure is repeated for all 5 dots in a pattern; then the holder is repositioned for the second pattern and the procedure repeated. Finally, the procedure is repeated for the third pattern. Following the adduction aiming, the holder along with a new pattern set is positioned to the right of the suited operator's arm and the procedure is repeated for an abducting aiming motion. The response measure is average aiming error (in millimeters) calculated separately for the abducting and for the adducting motion. Administrative time is estimated to be about 10 minutes for 3 operator-suit pressure conditions.

The measurement of wrist abductive and of wrist adductive strength is suggested through another simple, but specially constructed, device. The device is illustrated in Figure 7. The suited operator places the thumb side of the fist of his preferred arm against the platform and makes the strongest adducting motion possible. The procedure is repeated 3 times and the mean (inch pounds or inch ounces) is calculated. Then the procedure is repeated for the wrist abduction strength. Here, the other side of the wrist is employed. In administering this test, the subject's arm should be observed carefully and measures which are confounded with any movement other than wrist abduction or wrist adduction should be discounted. The total administrative time, assuming 3 operator-suit pressurization conditions, is estimated to be about 5 minutes.

To measure wrist abduction-adduction psychomotor coordination, the same tracking apparatus, described above for finger psychomotor coordination, is suggested. Here, however, a rotary knob controller is suggested, and the operator is required to grasp the knob controller with the fingers of his preferred hand fully extended. The wrist movements of the operator are limited, in this test, to abduction-adduction. Three tracking periods, each one being 30 seconds in duration, are suggested per suit pressurization condition. Scoring is again based on integrated time off target. The total administrative time is estimated to be the same as for the finger tracking--about 15 minutes.

We suggest that the range of movement be measured, for the wrist, through direct measurement--again with a millimeter ruler. Only abduction-adduction are measured in the Level I testing. The ruler is placed on a table top with the preferred arm of the operator placed in the position shown in Figure 8. The operator is asked to abduct his wrist fully and then to adduct it fully. In performing the pivoting motion, care must be exercised in order to prevent the hand of the subject from slipping, along the table top, from its pivot point. The first measure (full adduction) is taken at the outer edge of the index finger and one-half inch from the finger

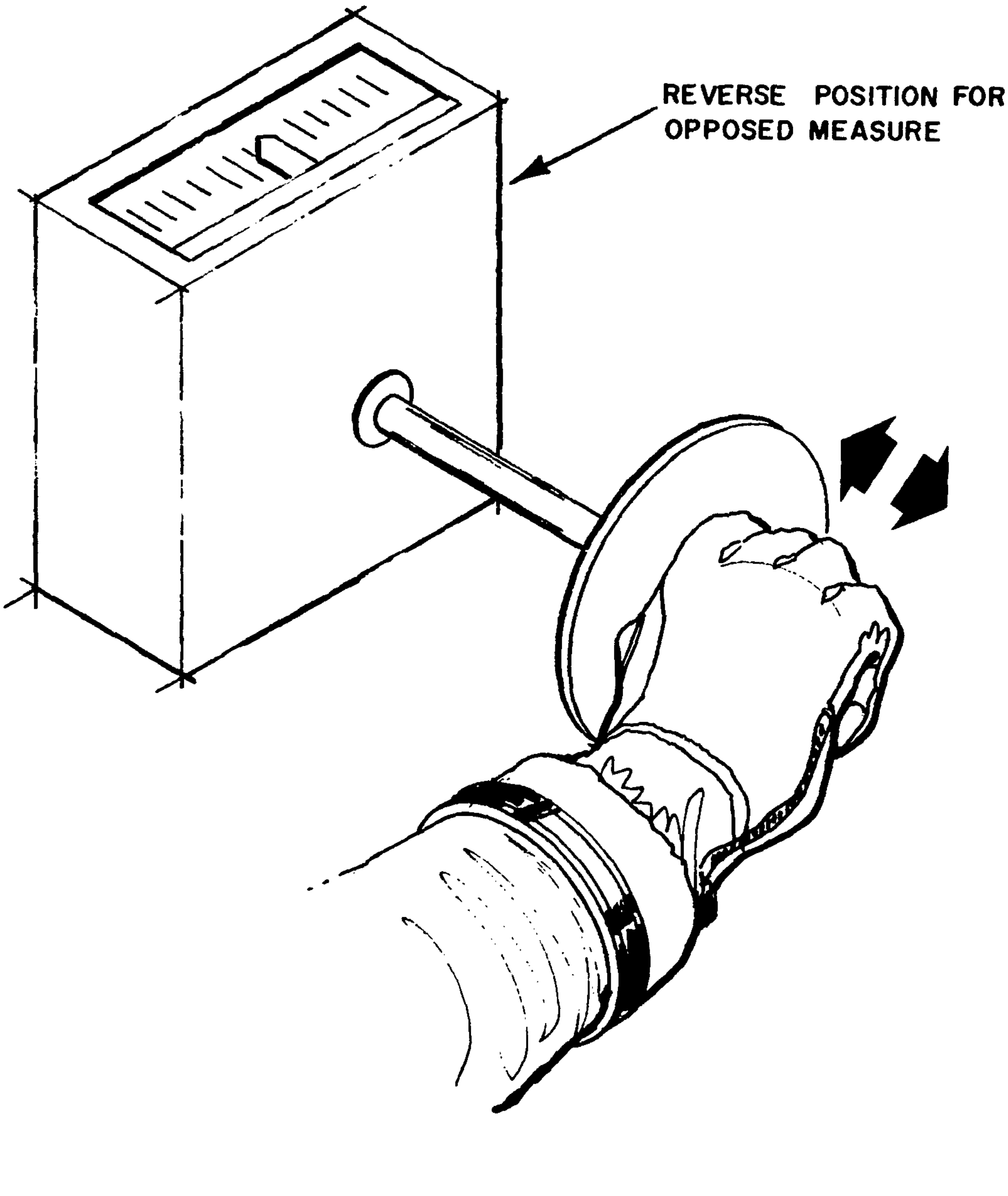


Figure 7. Wrist abduction-adduction strength measurement.

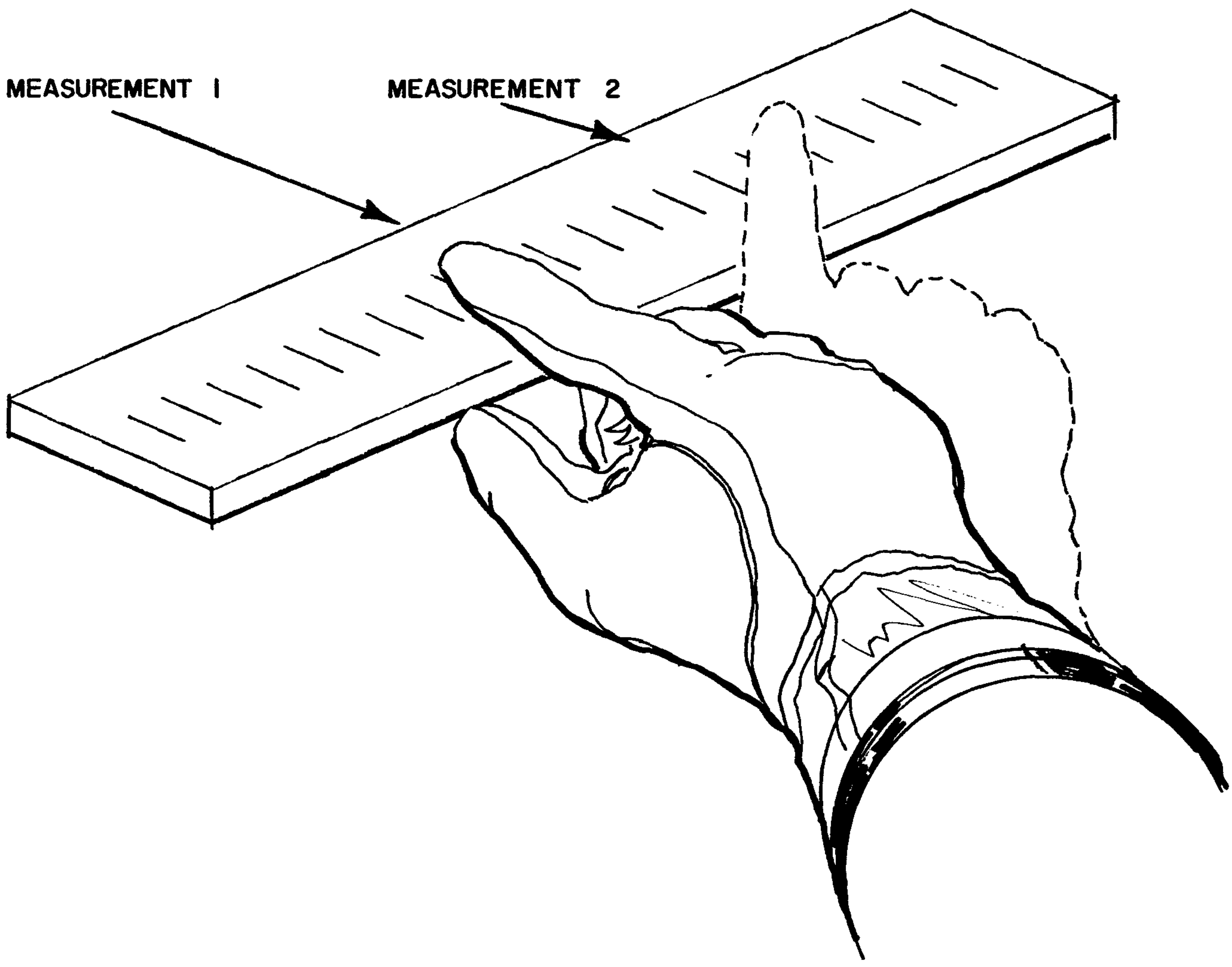


Figure 8. Wrist abduction-adduction range measurement.

tip (or glove tip). The second measure (full abduction) is taken at the same point. If the rotational sweep on abduction exceeds the edge of the ruler, a perpendicular may be dropped from the ruler's edge to the reference point of finger or glove and the second measurement made at the intersect of the perpendicular with the ruler's edge. The time for the completion of these measurements should be no more than 5 minutes for three suit-pressurization conditions.

Elbow Measurements

Elbow flexion-extension strength is measurable through the same apparatus that was employed to measure wrist strength. The fist of the standing suited subject's preferred arm is placed to the right of the apparatus, with the apparatus clamped in place at shoulder height. The subject's arm is fully extended and supported, as shown in Figure 9. The subject is asked to exert maximum pressure against the measurement plate. Force exerted is measured directly. This procedure is repeated three times. Then the subject is asked to flex his elbow fully, and his arm again is supported. The strength measurement device is placed in front of his fully flexed elbow, and the task of the subject is to exert maximum pressure by extending his elbow. Three measurements are similarly made. A mean extension and a mean flexion value is calculated. The time involvement for this test, across three suit-pressurization conditions, is estimated to be about 5 minutes.

It is suggested that psychomotor coordination for the elbow be measured through the same compensatory tracking apparatus (Figure 16, Appendix) that is employed for the prior psychomotor coordination measurements. For the elbow measurements, a stick controller is employed. Here, the subject is asked to keep his wrist rigid, to grasp the stick controller with his preferred hand, and to perform the tracking operation as before. For each suit-pressurization condition, three trials of 30 seconds each are suggested. Mean integrated time off target represents the response measure. Assuming three suit-pressurization conditions, the total administrative time is estimated to be 15 minutes.

The range of elbow movement is measured via a Leighton Flexometer (30). This instrument consists of a weighted, 360° dial and a weighted pointer, mounted in a case. The dial and pointer operate freely and independently; the movement of each is controlled by gravity. The instrument will record movement while in any position 20° or more off the horizontal and gives direct readings in degrees of rotational arc. The device has been available from: Leighton Flexometer, E1321 - 55th Street, Spokane, Washington, for a cost of $110. The flexometer is attached to the elbow, and the operator in the environmental protective assembly is asked to flex his elbow fully, The graduated scale is then unlocked, allowed to come to rest, and relocked. The subject is then asked to extend his elbow fully, the pointer unlocked, allowed to come to rest, and relocked. The dial indicates angular rotation directly.

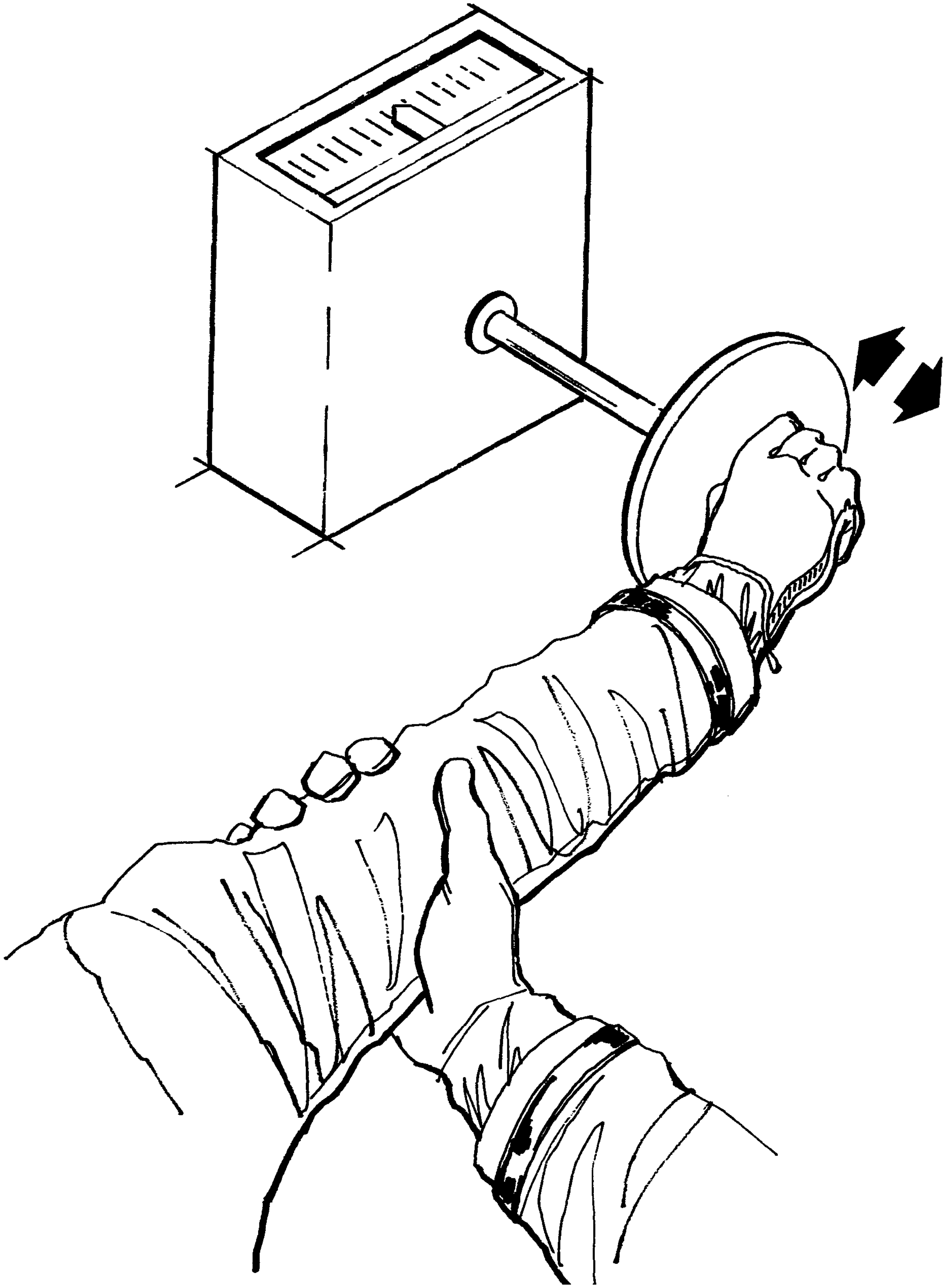


Figure 9. Elbow flexion-extension strength measurement.

Assuming one measurement at each of three suit pressurization conditions, the time for these measures should be no more than 5 minutes.

The static dimensions of the elbow are measured, at the elbow joint, at each of three suit-pressurization conditions. A tape measure, calibrated in inches or millimeters, is employed, and the measurement is made under three suit-pressurization conditions. The total time involvement should be no more than 5 minutes.

Shoulder Measures

Only two shoulder measures are suggested within the Level I testing. The reasoning behind the abbreviation of the number of measures in the shoulder area was discussed previously in this report.

For the shoulder area, the data suggest measurement of the range of shoulder flexion-extension, and direct measurement of the static dimensions of the shoulder area. Both measurements are made at the same location. The flexometer is placed at the side of the upper arm, halfway between the elbow and shoulder joints, and the tape measure determinations are made at the same locus. Each is made under three pressurization conditions. It is believed that both measures can be made in 10 minutes, assuming three suit-pressurization conditions.

Summary of Administrative Times for Level I Tests

The estimated administrative time for each of the various tests and measures involved in the Level I assessments is summarized in Table XV. Table XV suggests that a 2 hour administration time limit will probably be only slightly exceeded.

Level II Tests

Level II tests are administered in only those cases in which a particular suit assembly meets Level I minima or in which a more penetrating analysis is required. Since the Level I results can be anticipated to correlate highly with the Level II findings, Level II testing should probably not be entered into except as a deeper check which will provide increased reliability in the data on which the resultant recommendations are based.

Table XVI synthesizes the isolated body member-movement families and test areas suggested for inclusion in the Level II testing.

Table XV

Administrative Time for Level I Measures
(For three pressurized conditions)

Measure	Body Member	Estimated Time (Minutes)
Purdue Peg Board	Finger	15
Depression-elevation strength	Finger	15
Psychomotor coordination	Finger	15
Flexion range	Finger	10
Static anthropometry	Finger	5
Dexterity	Wrist	10
Abductive-adductive strength	Wrist	5
Psychomotor coordination	Wrist	15
Abduction-adduction range	Wrist	5
Flexion-extension strength	Elbow	5
Psychomotor coordination	Elbow	15
Flexion-extension range	Elbow	5
Static anthropometry	Elbow	5
Flexion-extension range	Shoulder	5
Static anthropometry	Shoulder	5
	Total	130

Finger Measures

To measure finger psychomotor coordination for flexion, we suggest a one-dimensional, compensatory tracking task. To confine the tracking to finger movement, we suggest a finger control as shown in Figure 16 (Appendix). The task of the suited operator is to perform the required tracking operation using only flexing-extending motions, over a 30 second period, with the index finger of his preferred hand. The test administrator records the integrated time off target. The 30 second tracking task is then performed with the suited operator using his middle finger for the tracking. The tracking continues, alternating fingers, until five tracking periods of 30 seconds each have been completed for each of the two fingers. It is estimated that 15 minutes will be required to administer this test.

Table XVI

Summary of Suggested Level II Tests

	Measurement Area and Test/Device				
Body Member-Movement	Dexterity	Strength	Psychomotor Coordination	Range of Movement	Static Anthropometry
Finger flexion	--------	--------	One dimensional tracking with finger wheel controller	---------	-------------
Wrist flexion-extension	Special apparatus	Special apparatus	One dimensional tracking with stick controller	Leighton Flexometer	-------------
Shoulder abduction-adduction	--------	---------	One dimensional tracking	Leighton Flexometer	-------------

Wrist Measures

The wrist flexion-extension dexterity measurement parallels that employed for the wrist abduction-adduction measurement. The same apparatus is used and the same "aim at and hit the dot" procedure is employed. However, in this case, the target holder is placed, first, 9 inches above the table top, with the first dot pattern directly over the suited operator's extended thumb and middle finger. The subject is instructed to flex his wrist and then, via an extending aiming motion, hit the first dot of the patterned set with the pencil point (see Figure 10). He then flexes his wrist and continues sequentially, employing the same procedure, through the remaining dots in the first pattern. Then, the holder is repositioned and the procedure is repeated for the second pattern of dots, then the procedure is repeated for the third set of dots. Following the extension dexterity measurements, the paper containing the dot patterns is placed on the table top and the dot aiming test is repeated for a flexing wrist motion. Mean miss distance is calculated separately for the flexing and for the extending motions. If three operator-suit pressurization conditions are involved, it is estimated that the testing time will be about 8 minutes.

Wrist flexion-extension strength is measured in a manner which is analogous to that employed for the wrist abduction-adduction strength measurement. For the strength of wrist flexion measurement, the suited operator places his fist above (on top of) the platform and makes the strongest flexing motion possible. While performing the flexion, the finger joints should be centered on the moveable platform. Care must be exercised to assure that the operator does not press down on the platform through the use of his forearm. This can be controlled by insisting that the forearm be held rigid and above the table top during the performance of the flexive act. For the measurement of wrist extensive strength, the apparatus is rotated and held 6 inches above the table top with clamps. The fist is placed under the platform, with the knuckles at the platform's midline. Then, the prior procedure is repeated. The scoring is in terms of the mean for each movement and, assuming three operator-suit pressure conditions, the administrative time for both sets of measurements is estimated to be about 5 minutes.

Wrist flexive-extensive psychomotor coordination is measured employing the same tracking apparatus and procedure as was employed for the finger depression-elevation measures. In the wrist tracking, the suited operator may perform the tracking either by grasping the stick control or by placing his fully extended index finger into the groove on top of the controller. The important points are that the elbow be held rigidly above the table top and that only wrist extensive-flexive motions are used during the test. If three 30 second trials are allowed for each of three suit-pressurization conditions, the administrative time is estimated to be about 10 minutes. Integrated time off target represents the suggested response parameter.

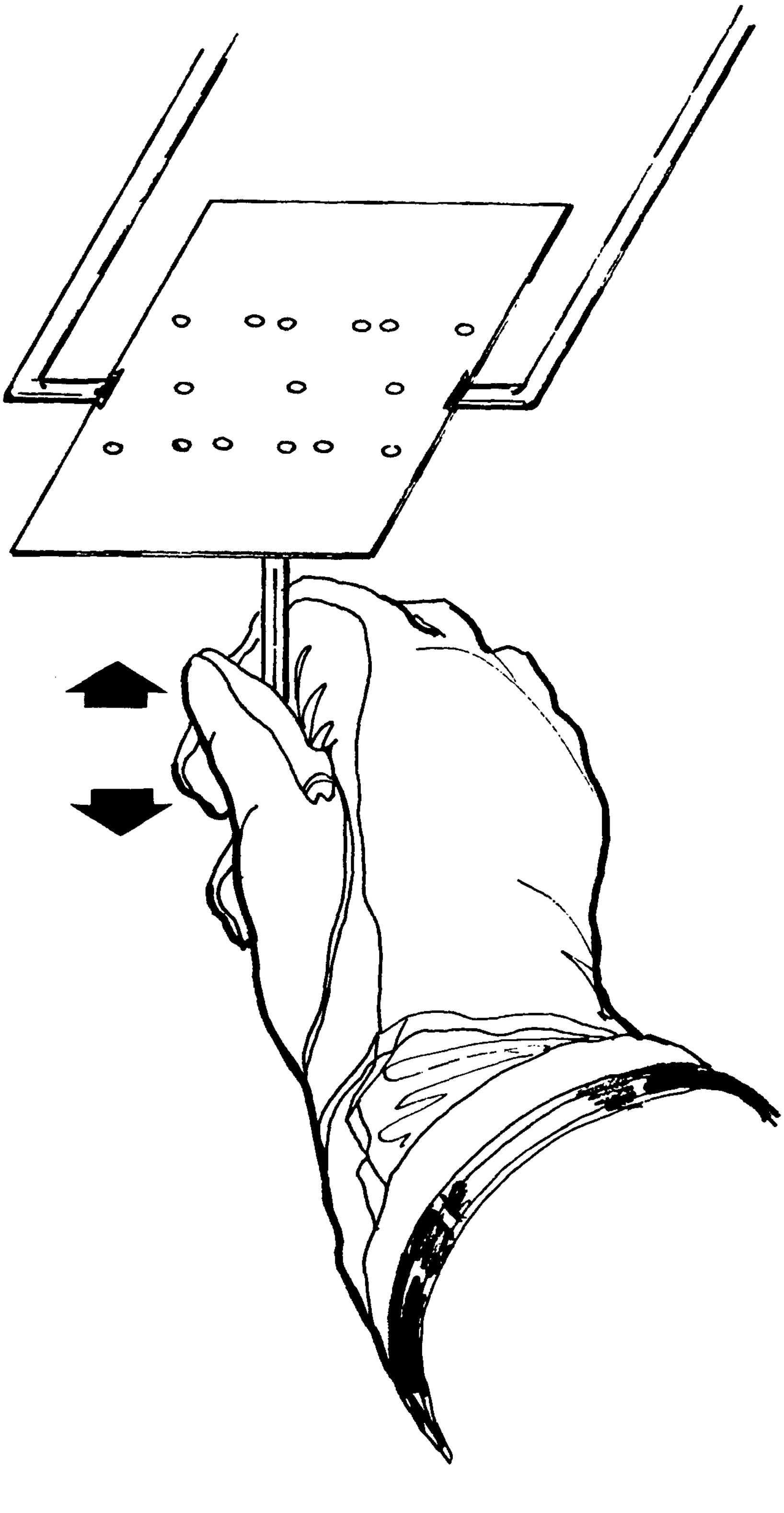


Figure 10. Wrist flexion-extension dexterity measurement.

The range of wrist extensive-flexive movement is measured, for the preferred arm, through the use of the Leighton Flexometer. The time involvement will be about 5 minutes.

Shoulder Measurements

Only two Level II shoulder measurements are involved: psychomotor coordination and range of movement. Both are concerned with abductive-adductive movements.

Shoulder abductive-adductive psychomotor coordination is measured via the same tracking apparatus and stick controller as for the elbow flexion-extension coordination. The controller package is rotated 90^{o} so as to permit the abductive-adductive tracking. The suited subject is asked to hold his wrist and elbow as rigid as possible during the three, 30 second tracking trials. Scoring, again, is based on integrated time off the target. Administrative time is estimated to be about 10 minutes for three suit pressurization conditions.

The range of shoulder abductive-adductive movement is measured via the Flexometer, which is strapped midway between the elbow and the shoulder. This measurement will take another 5 minutes.

Summary of Administrative Times for Level II Tests

A summary of the administrative times for the Level II measures is presented in Table XVII. The total estimated Level II testing time is 63 minutes.

Table XVII

Administrative Time for Level II Measures
(For three pressurized conditions)

Measure	Body Member	Estimated Time (Minutes)
Psychomotor coordination	Finger	15
Flexion-extension dexterity	Wrist	8
Flexion-extension strength	Wrist	5
Flexion-extension coordination	Wrist	15
Flexion-extension range	Wrist	5
Abduction-adduction coordination	Shoulder	10
Abduction-adduction range	Shoulder	5
	Total	63

Level III Tests

Level III testing represents a search for evaluative data in special situations or in situations in which a final check on mobility within a suit is required.

Our aim here, as for the Level I and Level II testing, is to isolate measures which will possess generality to many systems. However, when the compatibility of the operator-suit combination with a specific equipment system is under question, testing specifically related to the system involved may be warranted within Level III.

The Level I and the Level II testing ignored head movements or visual field measures. Visual field measurements may be made through any type of visual perimetric device and employing standard techniques. Such devices are available from a number of sources. Costs range upwards from about $36.

To measure head movements, a number of techniques have been previously suggested by others. The Woodson guide (31) suggests a simple optical method for plotting the head movement limits. All of the photographic techniques mentioned earlier, although time consuming, are appropriate. Siegel et al. (13) have previously described the performance of such measures through the use of a rotatable calibrated arc which can be tilted to various angles around a seat reference point. The forward end of the arc is supported by a mobile stand which possesses a pivotal point. To perform the required measurements, the arc is tilted to a series of angles and the furthest point along the arc which the suited subject can see (allowing head movements) is read from a calibrated arc. For the current purposes, we suggest using the Flexometer and simply measuring neck rotational range, neck flexion-extension range, and lateral flexion of neck.

Other Flexometer measurements suggested for Level III testing include:

1. flexion and extension of the right knee
2. flexion and extension of the right ankle
3. inversion and eversion of the right ankle
4. extension and flexion of trunk
5. lateral flexion of the trunk

Static anthropometric measurements suggested for inclusion in the Level III testing include:

1. external suit diameter at the midline of the knee cap under three pressurization conditions

2. external suit diameter at the umbilical level under three pressurization conditions

Within the Level III measures, we also suggest a final test of integrated mobility. Here, we suggest the following qualitatively scored and physiologically monitored demonstrations.

1. ladder climbing--a step ladder with eight rungs is placed against a wall. The angle of the ladder's top with the wall is 22^{o}. The subject is asked to ascend to the sixth rung and to descend to the floor. The sequence is repeated three times under each of three suit pressurization conditions.

2. barrel transit--the suited subject is asked to crawl through a barrel (which is free to roll). This is repeated three times, with each trial immediately succeeding the previous, under three suit pressurization conditions.

3. sitting down and standing up--the subject is asked to sit down on and stand up from a bridge chair three times in a row. The task is performed under each of three suit pressurization conditions.

4. stair walking--the suited subject is asked to walk up five steps, turn around, and descend to the floor. This task is performed without grasping a banister or side railing. This task is also performed under all suit pressures involved.

5. self righting--the subject is asked to lie prone on the floor. He is asked to roll over on his back and stand up. This is performed three times under each suit pressurization condition. The subject is then asked to lie on his back, roll over, and stand up. This task is also repeated three times under each suit pressurization condition.

A simple trichotomous scoring scheme is suggested for each of the above tasks. A score of 0, 1, or 2 would be assigned as follows:

0 = all three trials under a given pressurization condition not completed

1 = all three trials under a given pressurization condition completed in n + m seconds

2 = all three trials under a given pressurization condition completed in n seconds

Additionally, the energy expended in performing these tasks should be estimated over each set of three trials. The suggested method for performing this estimate is indirect but has been shown to be a useful one. Energy expenditure or heat production in work can be related to oxygen consumption which, in turn, is a direct function of heart rate. Table XVIII taken from Roth (32) illustrates these relationships and proposes the use of met values (1 met = 100 watts) for indices of energy consumption.

In the present instance, it is suggested that the ratio of pulse rate before task to that immediately after task completion be used as an index of degradation owing to the effect of the particular suit configuration-pressurization condition used.

The pulse can be measured through the use of a variety of standard transducers and related peripheral equipments. Some of these provide the required averaging while others fail to provide this feature. Examples are a wrist watch type counter and related chest mounted sensors, produced by the Waters Corporation and the cardiotachometer, employing a variety of sensors, manufactured by the American Electronic Laboratories.

A final check or demonstration of dexterity for simple coordinated acts may possess merit. Such simple demonstrations might include opening a package of cigarettes, paging through a book, sharpening a pencil, tieing a square knot, squeezing tooth paste on a tooth brush, or dialing a telephone.

Swept Area

While not directly related to mobility and dexterity measurement in full-pressure assemblies, it may be desirable, in certain circumstances, to determine the swept area required by a gloved, pressure suited hand.

Table XVIII

Relationship Between Energy Expenditure and Heart Rate

METS	WATTS	RATE OF ENERGY EXPENDITURE OR HEAT PRODUCTION: Kg.-cal. per min.	Kg.-cal. per hr.	BTU per min.	BTU per hr.	OXYGEN CONSUMED: Litters STP per min.	Litters STP per hr.	Grams per min.	Grams per hr.	HEART RATE Beats/min.
								-3.5	-210	175
9	-900									>
		12.5	-750	-50	-3000	-2.5	-150			175
8	-800									to
								-3.0	-180	150
7	-700	10	-600	-40	-2400	-2	-120			
								-2.5	-150	150
6	-600									to
		7.5	-450	-30	-1800	-1.5	-90	-2.0	-120	125
5	-500									125
								-1.5	-90	to
4	-400									100
		5	-300	-20	-1200	-1	-60			
3	-300							-1.0	-60	100
										to
										60
2	-200									
		2.5	-150	-10	-600	-0.5	-30	-0.5	-30	
1	-100									

Swept area is the space required by the gloved hand, under various pressurization conditions, to operate and manipulate panel and console controls. To measure the swept-area requirements for a specific suit-glove combination, the swept area recorder shown in Figures 11 and 12 is suggested. To use the device, the suited operator grasps a control (rotary knob, toggle, etc.) located at the bottom center of a 6 inch deep opening, approximately three inches in diameter. Concentric with the control are 12 movable vanes. When the control is operated, the test subject's hand displaces these vanes. Vane displacement causes a corresponding displacement of recording pens which trace the action on polar coordinate paper. Figure 13 shows a hypothetical tracing which might be generated when operating a rotary control under three different suit pressures. When the test is complete, the hand is removed and the back of the cabinet is opened. The plotting paper upon which the traces are made is removed from the device, and all maximal points on the trace lines are joined to form a graphic display of the sweep action and the swept area. Overlays of test profiles will produce an average sweep pattern for the various types and styles of controls.

Unusual Positions

Most of the tests and measures mentioned above are administered with the suited subject in a comfortable chair. In some cases, the ability of the subject to perform various acts when his body is in an unusual position may be warranted. For these cases, any of the Level I or Level II tests may be administered, as appropriate. Unusual postures which the subject may be asked to assume while performing the tests are: full flexion of the trunk, full lateral flexion of the trunk, squatting, sitting with trunk fully rotated in a direction which is opposed to the direction of the preferred hand and with the nonpreferred arm fully elevated, and sitting with trunk fully rotated in a direction which is opposed to the direction of the preferred hand and with the nonpreferred arm fully depressed, or standing on a steep incline.

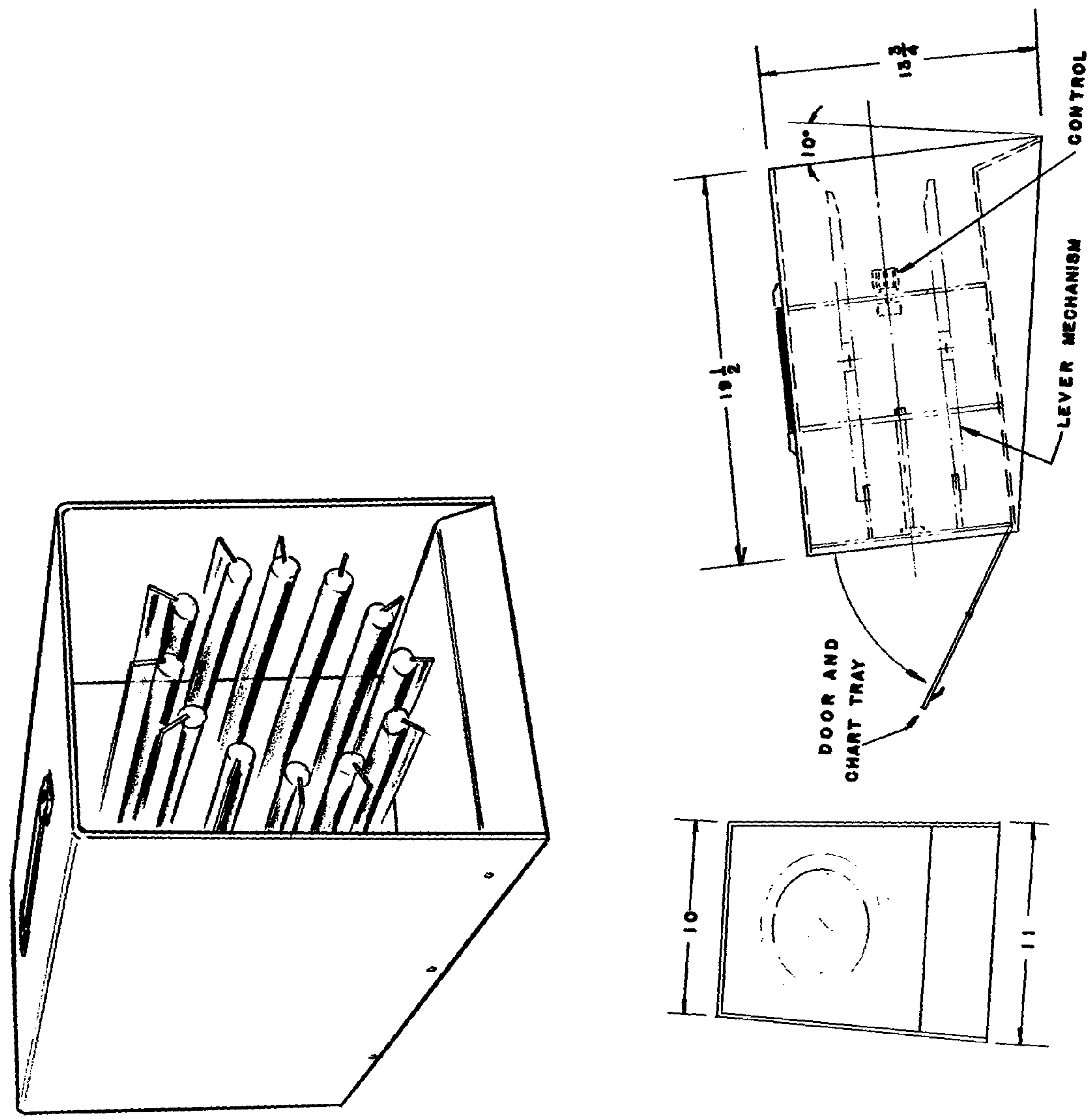


Figure 11 Swept area recorder (schematic).

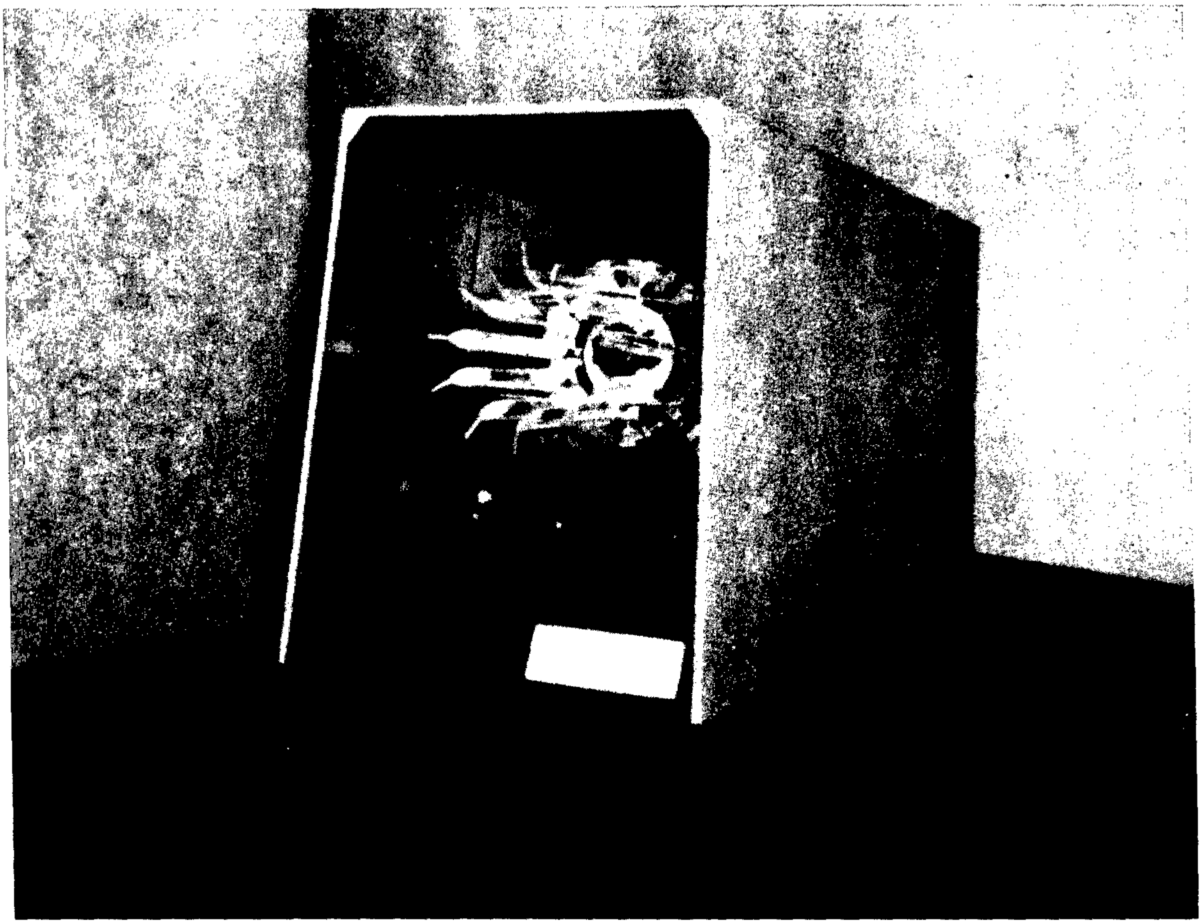


Figure 12. Swept area measurements device.

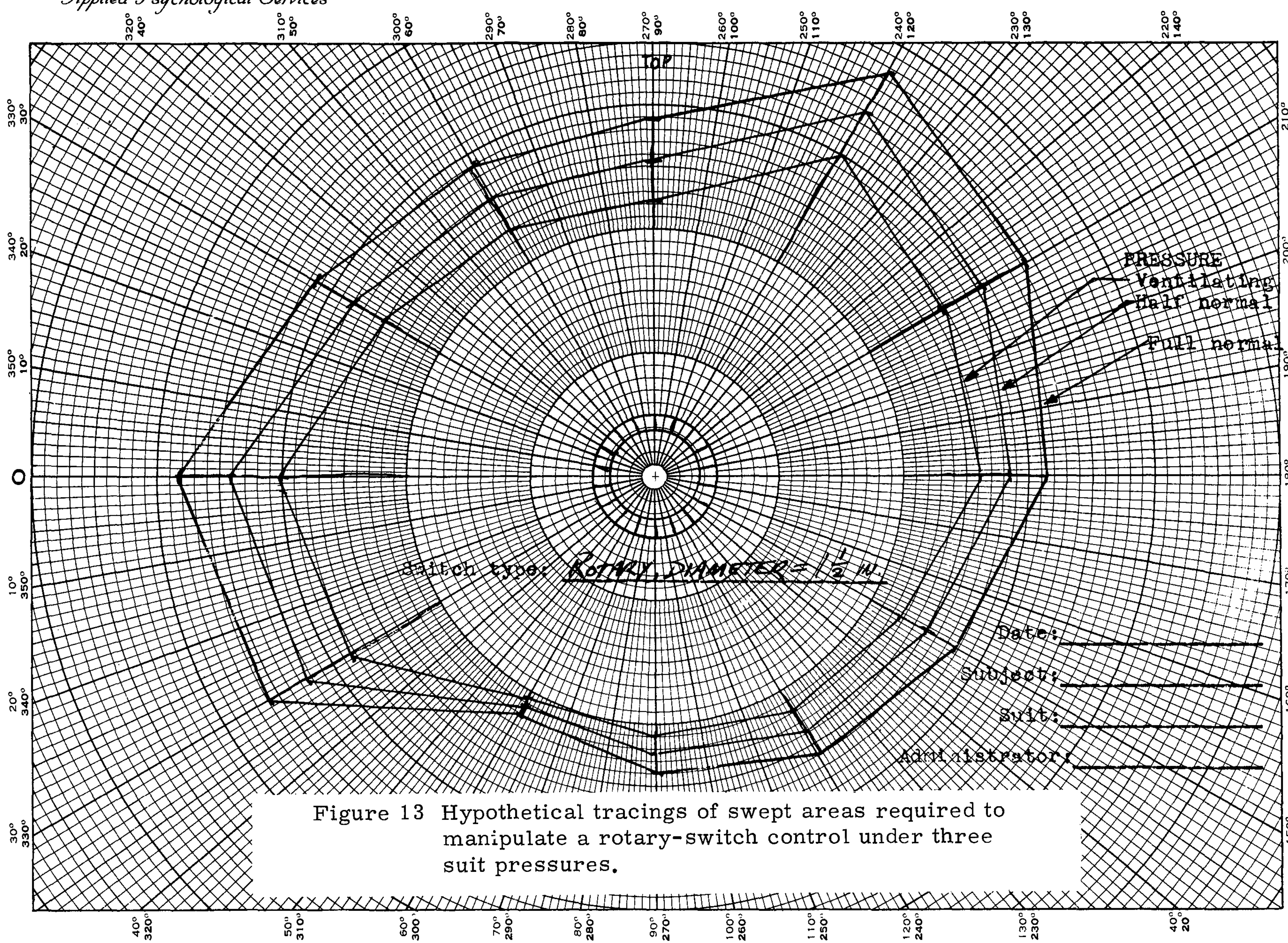


Figure 13 Hypothetical tracings of swept areas required to manipulate a rotary-switch control under three suit pressures.

SECTION IV

ADMINISTRATIVE AND SCORING COMMENTS

Section III of this report discussed a set of suggested measures for evaluating operator performance in full-pressure suit assemblies. Section IV elaborates on the concepts and considerations presented in Section III by presenting a series of comments related to the administration and scoring of the tests and measurements discussed earlier. Many of these elaborative comments constitute areas of interest for study and final determination, during initial pretest and evaluation of the suggested portable test battery.

Suited Subject Selection, Experience and Training

When comparatively evaluating two or more full-pressure suit assemblies, the same subject should be used for all tests and measures. If different subjects are involved, they should be matched anthropometrically. While it will probably never be possible to match subjects on a number of anthropometric dimensions, matching should take place on at least standing height and on weight.

Moreover, the subject must have received formal training in pressure suit use and employment. Not only are aspects related to the bodily safety of the suited subject involved, but a suit will not be employed correctly by the naive user. We are aware of no data relevant to the solution of the problem of how much actual training and experience a subject needs in a full-pressure suit before he can use the suit within the maximum efficiency of the suit. Certainly, recent extra vehicular excursion experience, for space vehicles, suggests that even the maximum previously given has not been sufficient in either quality or quantity. However, anecdotal reports suggest that at least for the earth's environment, subjects' confidence in the protective assembly and their ability to perform most of the acts permitted by the suit reaches an acceptable level after about 15 hours of experience in a suit.

Suit Pressure and Suit Considerations

Changing the suit-pressurization level more or less continuously over a brief time interval has been known to produce discomfort to the suited subject. On the other hand, from the point of view of ease of test and measurement administration, it would be most convenient to administer a test under all suit pressurization conditions involved, put the test

away, and move on to the next. Until further data are available on the extent of discomfort brought about by frequent changes in suit pressure and on the effects of this discomfort on the measures involved, we suggest completing all tests relative to one suit-pressure condition and then going to the next. Although this latter procedure will be less convenient to the test administrator, it will help to lessen measurement confounding. Possibly, a compromise over the two approaches will be the most practical and will help to distribute any sequence effect, attributable to pressurization sequence, equally over the data.

Due to the hazard associated with the use of 100 percent oxygen, we suggest that the pressurization and life support supply be breathing air. Adequately pure breathing air is available from most oxygen supply houses.

Throughout the previous chapter, we suggested the administration of all tests and measures under each of three suit-pressurization conditions. These are: (1) normal ventilating pressure (probably 0.25 psi) for a suit, (2) a pressure intermediate (probably 2.0 to 3.0 psi) between the normal ventilating pressure for the suit under consideration and the maximum pressure under which the suit will be used, and (3) the maximum pressurization condition (3.7 to 5.5 psi) under which the suit will be used. Some persons may assert that the employment of an intermediate pressure is unrealistic and time wasteful--and accordingly unwarranted. We contend that the measurement of three points along the pressurization continuum provides an intermediate reference which is important in the analysis of trend lines. We argue that a trend line based on only two points is meaningless, at least theoretically.

Moreover, the suit(s) involved in any evaluation which aims to be more or less thorough should fit the subject. Thus, special tailoring of the suit under consideration, for the operator involved in the testing, may be required.

Test Administrator Training

One consideration involved in the selection of the suggested tests and measurements was the sophistication level of the anticipated test administrators(s). The goal was to try to limit the suggested techniques to those which could be employed by persons with no more than a bachelor's degree and, if possible, a lower educational background. We believe that the suggested tests and measurements have met this goal, to a greater or lesser extent. Nevertheless, some training in the principles of standardized test administration will be required. Such training would include subject-matter such

as the maintenance of constant test conditions, standard methods for presenting instructions, the methods for scoring the tests, use of the various equipment, and use of scoring sheets. Moreover, the test administrator(s) should be trained in pressure suit use and employment including methods for donning and doffing, safety precautions, and the purpose of various tie downs, electrical connectors, and hose connectors.

The development of a standard test administrator's manual would also be helpful in this regard. Such a manual could be used to serve an instructional purpose as well as to help to preserve the maintenance of proper test and scoring procedures. When scoring sheets are developed, space should be allowed for the test administrator to enter any remarks or comments regarding the conditions of test or regarding factors, he has observed and believes to be salient in regard to a specific test condition, not reflected by the more quantitative data.

Comparison of Suits

We have suggested a number of tests and measures for employment under a number of suit pressurization conditions. Each test or measure will yield a number which, we maintain, will serve as an indicator of the effect of the suit on a given body member-movement family under a given pressurization condition. The open problem is how to employ these obtained numerics for the comparative evaluation of a given pressure-suit assembly with one or several other suit assemblies.

The numerics (or a subset of the numerics) derived from one suit will constitute a profile. For an alternate suit or an alternate configuration of the same suit, the numerics will constitute a second profile. Assuming that the same measures have been obtained on each suit, the problem becomes that of deriving a technique for comparing the two profiles quantitatively.

We suggest that, for any evaluation, the test and measurement battery be administered to the subject (who will be employed in the suit evaluation) in the shirt-sleeve condition. The profile for the subject's performance in the shirt-sleeve condition will then become the profile against which profiles of test and measurement results in various suit pressurization conditions are compared.

The problem in profile comparison is that two profiles can be similar (or different) in shape (configuration), in elevation (intensity or extensity), or both. If we consider only shape, we consider "relative" similarity. An

example of a statistic which measures shape alone is the rank difference correlation. If we speak of "absolute" similarity or difference, then elevation comes into the picture. While in many clinical situations, an evaluation on the basis of shape alone is satisfactory, and possibly desirable, it seems that elevation is meaningful in the current context. For example, the difference index of Meehl (33) is not useful in the current context, since this index reflects shape but neglects elevation. The index of profile similarity of DuMas (34) is, for the same reason, not useful for the purposes here considered.

However, there are at least two measures available which consider both shape and elevation, the D coefficient of Osgood and Suci (35) and the coefficient of pattern similarity of Cattell (36). However, Cattell's coefficient of pattern similarity, while computationally more elegant than the D coefficient, is dependent upon standard scores. Standard scores probably represent a desirable but not practically attainable commodity when pressure suit assemblies are involved. Accordingly, the present report focuses on the D coefficient.

The D coefficient, which appears to be almost the same as the "precise profile method" of Toops (37), is based on the geometric principle that in a space composed of N mutually orthogonal dimensions, the distance between the two points is equal to the square root of the sum of the squared differences between the coordinates of the points on each dimension. Profiles may be conceived as points in N dimensional space (in the present context, N = number of tests and measurements). The distance between corresponding points serves as a measure of similarity:

$$D = \sum_{i}^{N} d_{je}^{2} .$$

In this formula, $d_{je} = X_{ij} - X_{ie}$, where X_{ij} and X_{ie} are the corresponding scores in the shirt sleeve and pressurized condition on test or measure i. The coefficient obtained is arbitrary and its value will depend on the number of tests and measures involved. Moreover, the coefficient makes the assumption that the tests and measures employed are uncorrelated. In practice a D value would be calculated for each suit pressurization condition profile in comparison with the shirt sleeve profile. Thus, if normal ventilating and two suit pressurization conditions are involved, per suit under consideration, three computations of D are required. If two suits are involved, six computations of D would be required. Each suit would be compared with the shirt sleeve performance. The suit is preferred which gives the lowest D value under the anticipated conditions of suit employment. For example, the D value for 5.5 psi suit pressurization might have little meaning for a suit to be used at an altitude of 60,000 feet. Averaging D values is not recommended. However, the averaging of D^2 values is possible.

Of course, if individual subscore comparisons are wanted for a set of suits under comparative pressurization conditions, the test scores for an individual operator can be compared directly. If an index of performance deterioration is wanted for a given suit, under a given pressurization condition and for a given test or measure, the ratio of performance in the pressurized state to performance with the shirt-sleeve condition can be calculated.

Final Comments - Future Steps

We have attempted to describe a portable battery for assessing mobility and dexterity in full-pressure suits. Even assuming the adequacy of our methodological approach and the measure selected, we can not assert that a standardized battery has been achieved. We can assert that the suggested battery possesses an internal structure which is synthesized from the movements and body members involved in actual pressure suit employment. Moreover, the proposed measures are relatively "pure." Many of the previous pressure suit evaluations have been confounded across movements and body members. To those who argue that the purity of our measures constitute their greatest disadvantage (since the interaction effects are lost), we answer that the Level III testing should isolate any interactive effects present. Moreover, the suggested approach will yield answers regarding specific areas for improvement of a given pressure suit assembly. The more global approaches fail to yield this type of information as specifically. We also note that the proposed battery may provide a basis for formulating performance requirements, for the pressure suited operator, in specification form--and in a form which can be tested to determine whether or not the specification has been met.

To progress from the present conceptual formulation to a final standardized battery, a number of future steps are indicated. These include, but are not limited to, preliminary assembly of the battery, trial, revision, assembly in final form, determination of various psychometric reliability indices, and test manual development.

SECTION V

DISCUSSION

The goal of the present study was to isolate and describe the content for a portable battery which can be employed for assessing human performance in full-pressure suit assemblies. A literature review was performed to define those areas which previous investigators have considered important in such evaluations. The literature reviewed suggested that the area most frequently involved in full-pressure suit evaluations are: dexterity, strength, psychomotor coordination, range of movement, and static anthropometry. As a second step, a set of task analyses was performed to determine the body members and the movements of these body members which are most frequently employed in advanced vehicles. Analyses were performed for the F-111 aircraft, the APOLLO space vehicle, and a lunar exploration module. On the basis of these analyses, seven body member-movement families, which constitute 97 percent of the body member-movement involvement in these vehicles, were isolated. These were: finger flexion, finger depression-elevation, wrist abduction-adduction, wrist extension-flexion, elbow extension-flexion, shoulder abduction-adduction, and shoulder extension-flexion.

A set of tests and measurements, reflecting the isolated areas of interest, as indicated by the literature review, was then suggested for each of the seven body member-movement families. The suggested tests and measures were described and methods for scoring and administering the measures were presented. The suggested testing is divided over three levels. Level I tests are the most extensive and were suggested for all administrations. Level II tests and measures were suggested as being useful for suits which pass Level I criteria or for use on occasions which require a more penetrating analysis. Level III testing represents a search for evaluative data in special situations in which a final check on mobility seems desirable. The total time to administer the tests and measures for the first two levels is as follows: Level I--130 minutes, Level II--63 minutes. The time for the Level III testing will vary with the extent of the Level III testing believed necessary.

It was suggested that comparative evaluations be made employing the same suited subject for all pressure suits involved and, if this is not possible, anthropometric matching was viewed as necessary. The importance of formal training of test subjects and test administrators in pressure-suit use and employment was pointed out. Other aspects of test administration, including choice of three suit-pressurization conditions, sequence of pressurization, and standardization were discussed.

Integrated comparative scoring on the basis of the D coefficient was suggested. This statistic considers both the shape and the elevation of the profiles involved. In the present context, it was suggested that the profile for performance in the bare-handed condition be compared with performance in each of the pressure-suited conditions.

The advantages of the present approach were held to be inherent in the "purity" of the measures involved, the ability to yield answers regarding specific areas for improvement of a given suit, and the ability to provide performance specifications for the pressure-suited operator.

To progress from the present conceptualization to a final standardized battery, a number of future steps were indicated. These included preliminary assembly of a test battery, trial, revision, assembly in final form, determination of various psychometric reliability indices, and test manual development.

APPENDIX

Compensatory Tracking Device

APPENDIX

COMPENSATORY TRACKING DEVICE

The tracking apparatus mentioned in various places throughout this report is diagrammed in Figure 14. This is the general form for a compensatory tracking system. The operator's task is to minimize the discrepancy between the fixed reference and the moving target.

The difference between the input signal to the system (forcing function) and the state of the controlled element is displayed as error (discrepancy) to the operator.

A common method of providing a compensatory tracking task, and the one proposed here, is shown in Figure 15. The input signal generator supplies the required variation in voltage to displace the signal cursor from the reference line. The subject's control allows the operator to apply a compensating voltage, through a linear potentiometer, to restore the signal cursor to the reference line. The subject's task, then, is to null changes continuously in the input signal and maintain the display line at the horizontal center of the display (a cathode ray oscilloscope).

A tracking task can be made as easy or as difficult as desired by varying the frequency and amplitude of the forcing function. For the present application, a continuous loop magnetic tape of 10 or more minutes duration could contain the forcing function. The subject is unlikely to learn the pattern of random appearing samples from such an input in the course of the proposed tests.

The nature of the signal on the tape recorded input could be an amplitude modulated, audio frequency signal, followed by a half wave rectifier filter, prior to the cathode tube display. The frequency of the amplitude modulation should be random within the tracking capabilities of human operators, i. e., about 0-5 cps. The control dynamics of the system are somewhat unimportant, since one is only concerned with relative error scores.

The scoring of error is accomplished through a sensor, which actuates a relay, whenever the signal is outside the prescribed tolerance limits. The out-of-tolerance, time off target, is recorded by an accumulating timer.

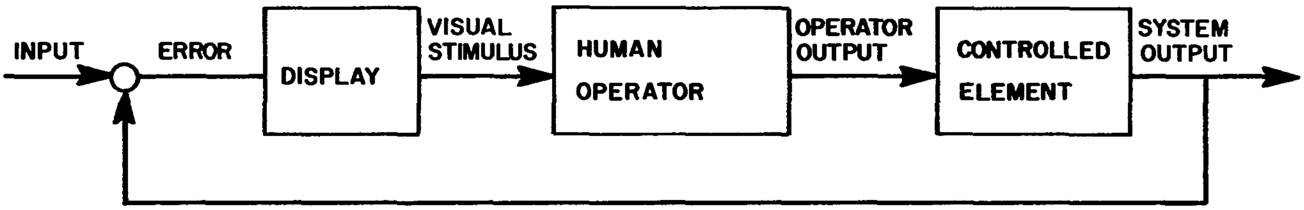


Figure 14. General diagram of compensatory tracking system.

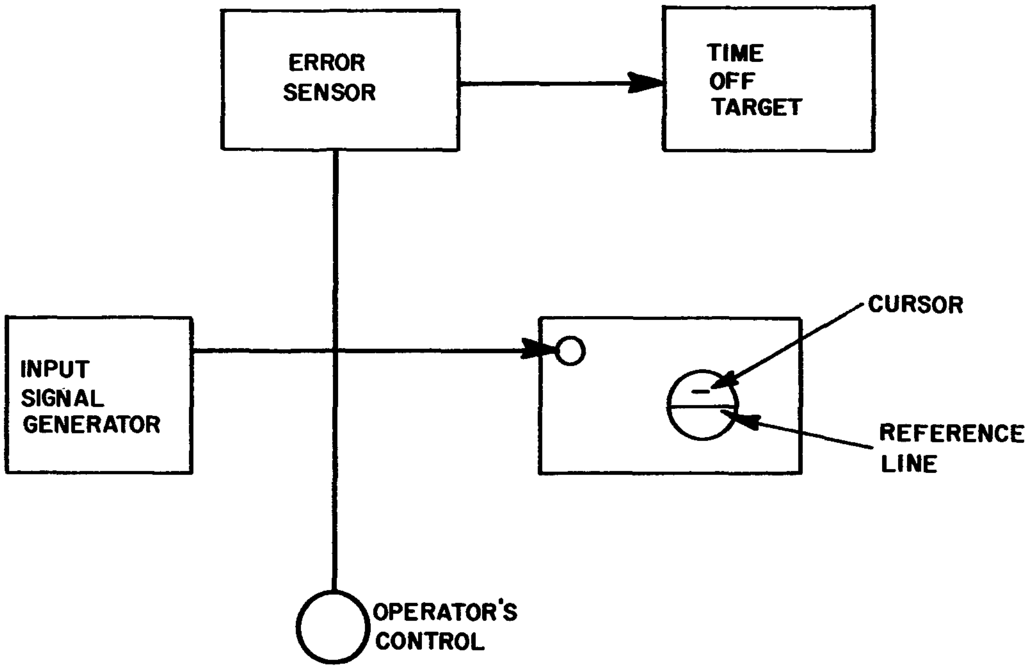


Figure 15. Block diagram of suggested tracking apparatus.

The basic operator's control for the device is the shaft of the potentiometer which controls the compensating voltage. The several control types, discussed in the body of the report, would be connected to the potentiometer shaft by any easy connect-disconnect method and by direct mechanical linkage to accomplish the desired control movement conditions. Figure 16 illustrates the different linkages required.

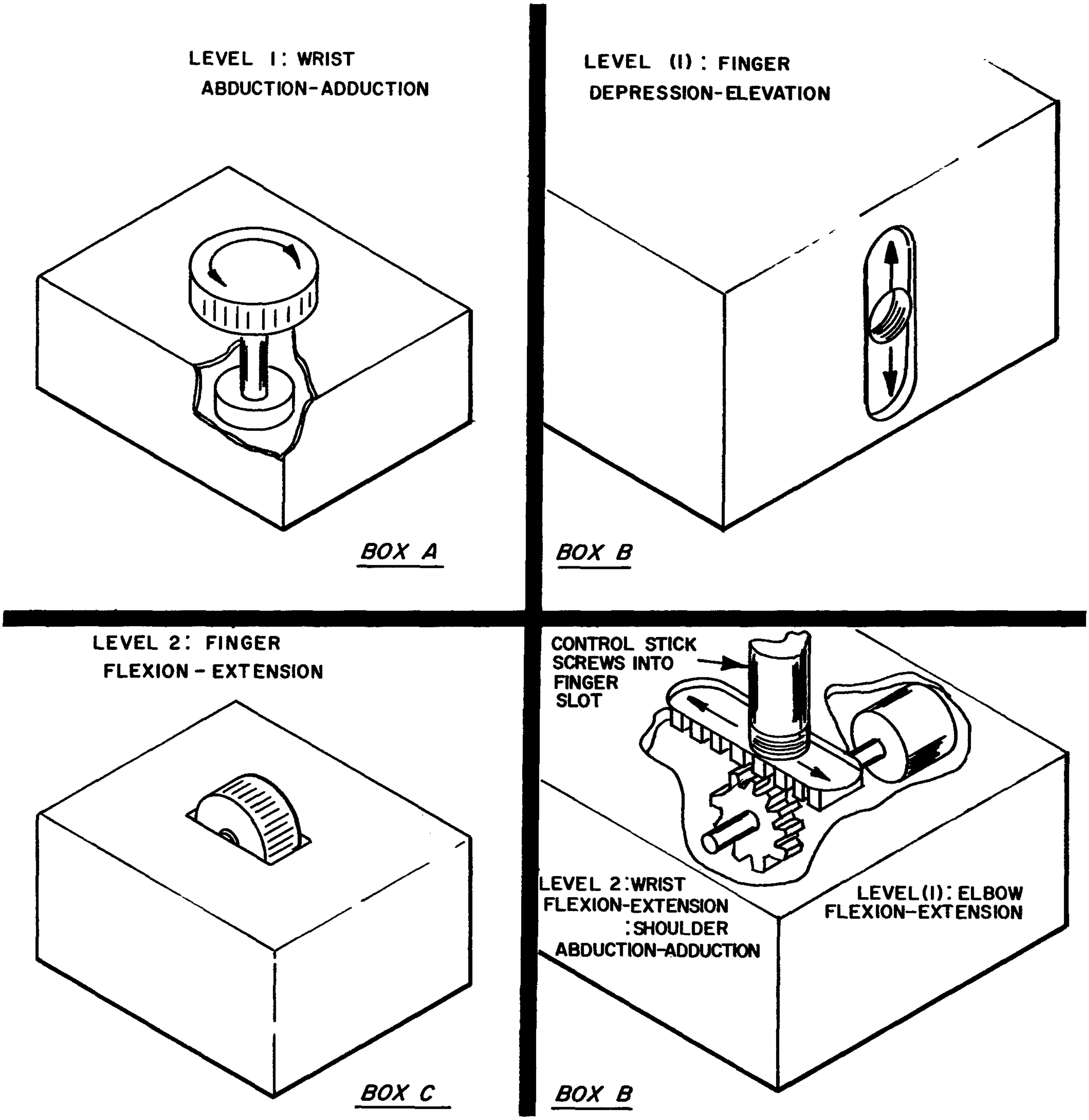


Figure 16. Controls and linkages required for tracking apparatus.

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13. ABSTRACT

Recommendations for a portable battery of tests to assess human mobility in full-pressure suits are presented. The literature was reviewed to determine the types of instruments and tests employed by prior investigators. Task analyses were performed on three advanced vehicles to determine the body member-movement families most frequently involved. A set of tests and measurements is suggested for those member-movement families found to be most frequently involved in advanced flight. Necessary future steps for realizing the portable battery are suggested.

The test battery recommended includes the Purdue Peg Board for finger dexterity, a specially designed apparatus for the strength of various body movements, a single dimension tracking task for various coordination tests, a Leighton Flexometer, and direct measurement devices for range of movement and static anthropology measurements.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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